



US009362952B2

(12) **United States Patent**
Myung et al.

(10) **Patent No.:** **US 9,362,952 B2**
(45) **Date of Patent:** **Jun. 7, 2016**

(54) **APPARATUSES AND METHODS FOR
ENCODING AND DECODING OF PARITY
CHECK CODES**

(71) Applicant: **SAMSUNG ELECTRONICS CO.,
LTD.**, Suwon-si (KR)

(72) Inventors: **Se-ho Myung**, Yongin-si (KR); **Hong-sil
Jeong**, Suwon-si (KR); **Kyung-joong
Kim**, Suwon-si (KR)

(73) Assignee: **SAMSUNG ELECTRONICS CO.,
LTD.**, Suwon-si (KR)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 42 days.

(21) Appl. No.: **14/303,856**

(22) Filed: **Jun. 13, 2014**

(65) **Prior Publication Data**

US 2014/0372826 A1 Dec. 18, 2014

Related U.S. Application Data

(60) Provisional application No. 61/862,633, filed on Aug.
6, 2013, provisional application No. 61/839,080, filed
on Jun. 25, 2013, provisional application No.
61/835,084, filed on Jun. 14, 2013.

(30) **Foreign Application Priority Data**

May 15, 2014 (KR) 10-2014-0058323

(51) **Int. Cl.**
H03M 13/00 (2006.01)
H03M 13/11 (2006.01)
H03M 13/03 (2006.01)

(52) **U.S. Cl.**
CPC **H03M 13/1165** (2013.01); **H03M 13/036**
(2013.01)

(58) **Field of Classification Search**

CPC H03M 13/1165; H03M 13/036; H03M
13/255; H03M 13/6552; H03M 13/271;
H03M 13/2707; H03M 13/1185

USPC 714/758, 759
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,502,987 B2 3/2009 Kyung et al.
8,190,981 B2* 5/2012 Jeong H03M 13/1165
714/746

(Continued)

FOREIGN PATENT DOCUMENTS

EP 2536030 A1 12/2012
JP 2012151520 A 8/2012
KR 10-2005-0118056 A 12/2005
WO 2012099398 A2 7/2012

OTHER PUBLICATIONS

International Search Report dated Oct. 8, 2014 issued by Interna-
tional Searching Authority in counterpart International Patent Appli-
cation No. PCT/KR2014/005203.

(Continued)

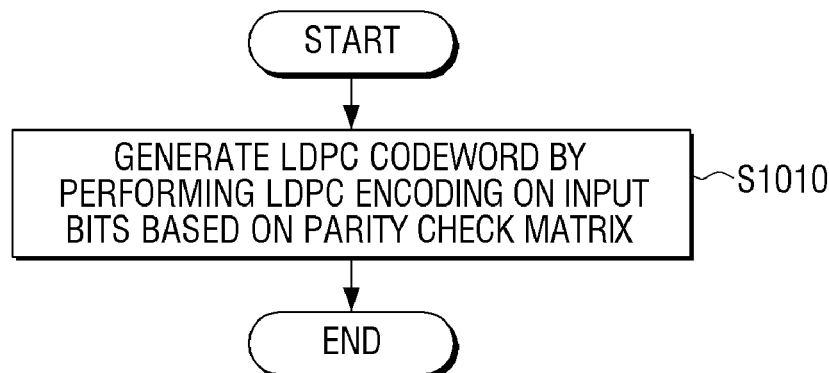
Primary Examiner — Christine Tu

(74) *Attorney, Agent, or Firm* — Sughrue Mion, PLLC

(57) **ABSTRACT**

An encoding apparatus is provided. The encoding apparatus
includes: a low density parity check (LDPC) encoder config-
ured to generate an LDPC codeword formed of 16200 bits by
performing LDPC encoding based on a parity check matrix,
wherein the parity check matrix includes an information word
sub-matrix and a parity sub-matrix, the information word
sub-matrix being formed of a plurality of column groups each
including 360 columns and being defined as a table indicating
a position of one (1) present in each 360-th column.

20 Claims, 11 Drawing Sheets



US 9,362,952 B2

Page 2

(56)

References Cited

U.S. PATENT DOCUMENTS

8,972,834	B2 *	3/2015	Eroz	H04L 1/00 714/790
9,135,108	B2 *	9/2015	Shinohara	G06F 11/10
2009/0070652	A1	3/2009	Myung et al.	
2011/0047435	A1	2/2011	Eroz et al.	

2013/0297992 A1 11/2013 Yamamoto et al.

OTHER PUBLICATIONS

Written Opinion dated Oct. 8, 2014 issued by International Searching Authority in counterpart International Patent Application No. PCT/KR2014/005203.

* cited by examiner

FIG. 1

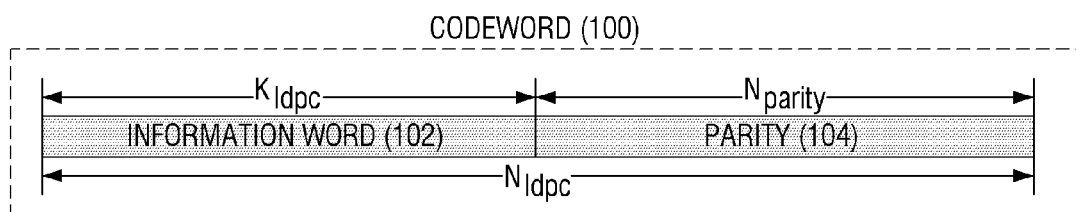


FIG. 2

$$H_1 = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 & 0 & 1 \end{bmatrix}$$

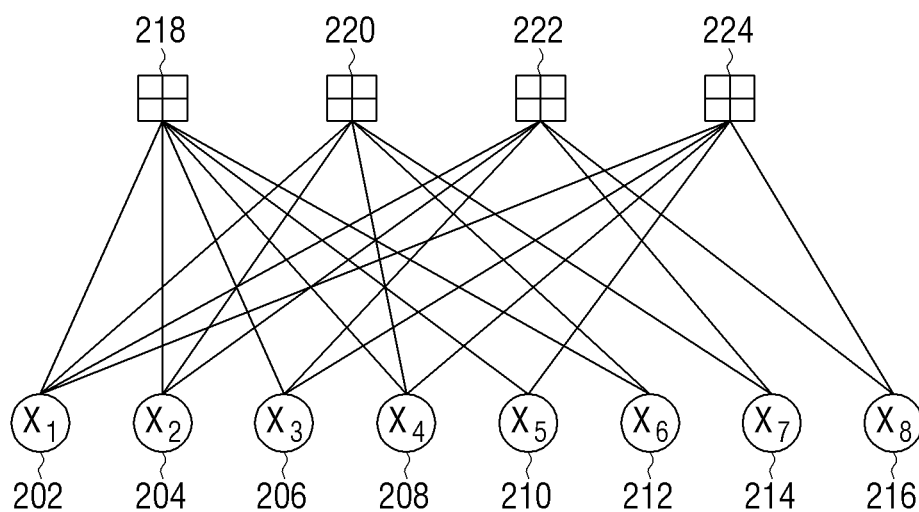


FIG. 3

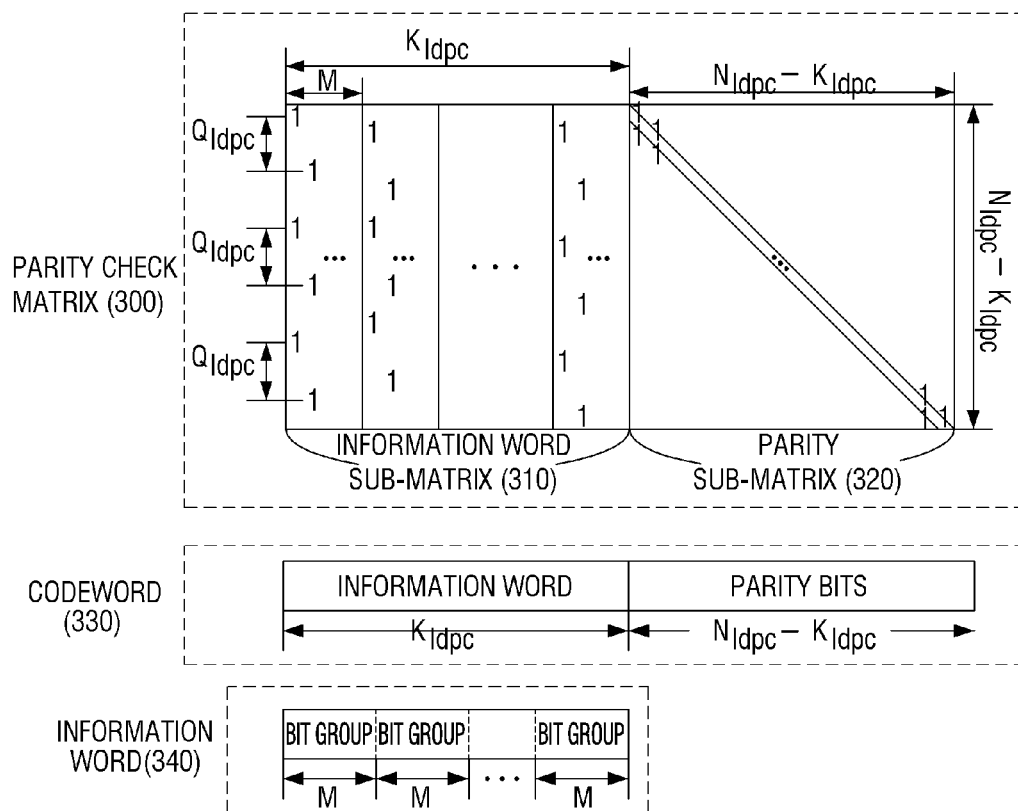


FIG. 4A

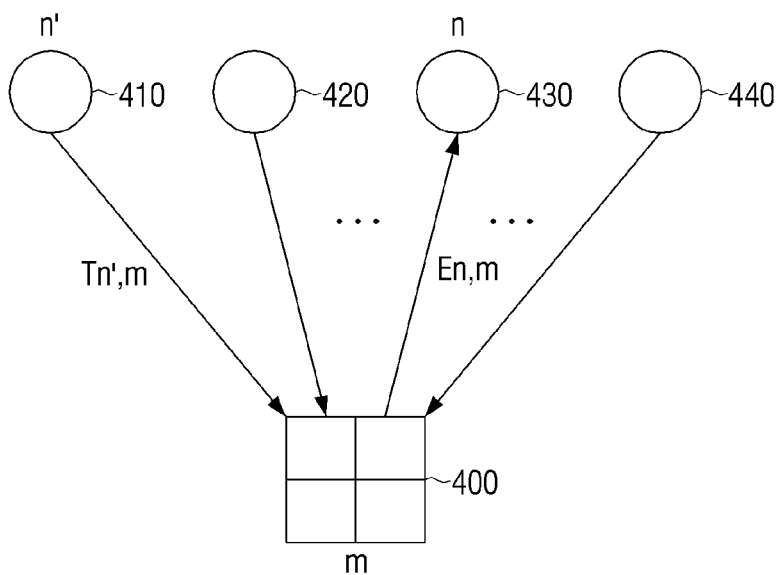


FIG. 4B

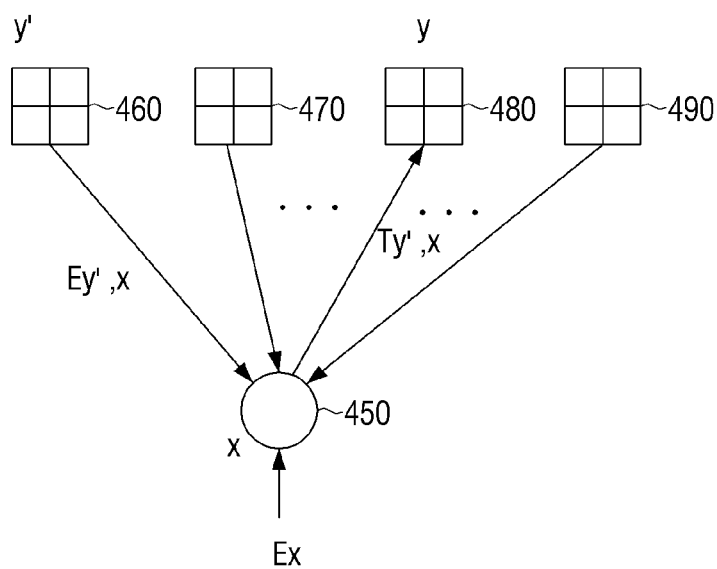


FIG. 5

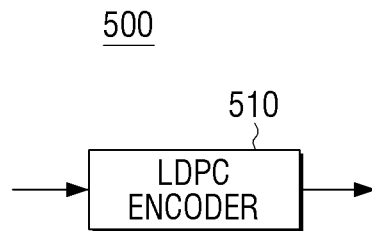


FIG. 6

600

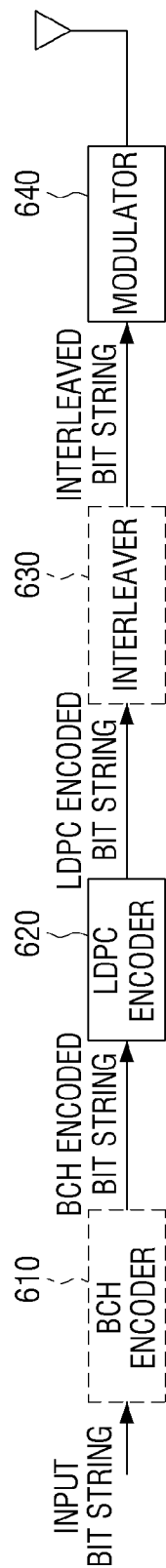


FIG. 7

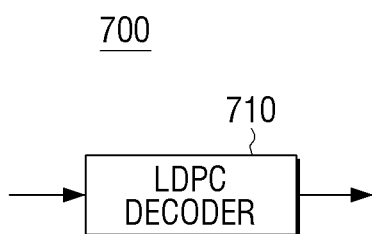


FIG. 8

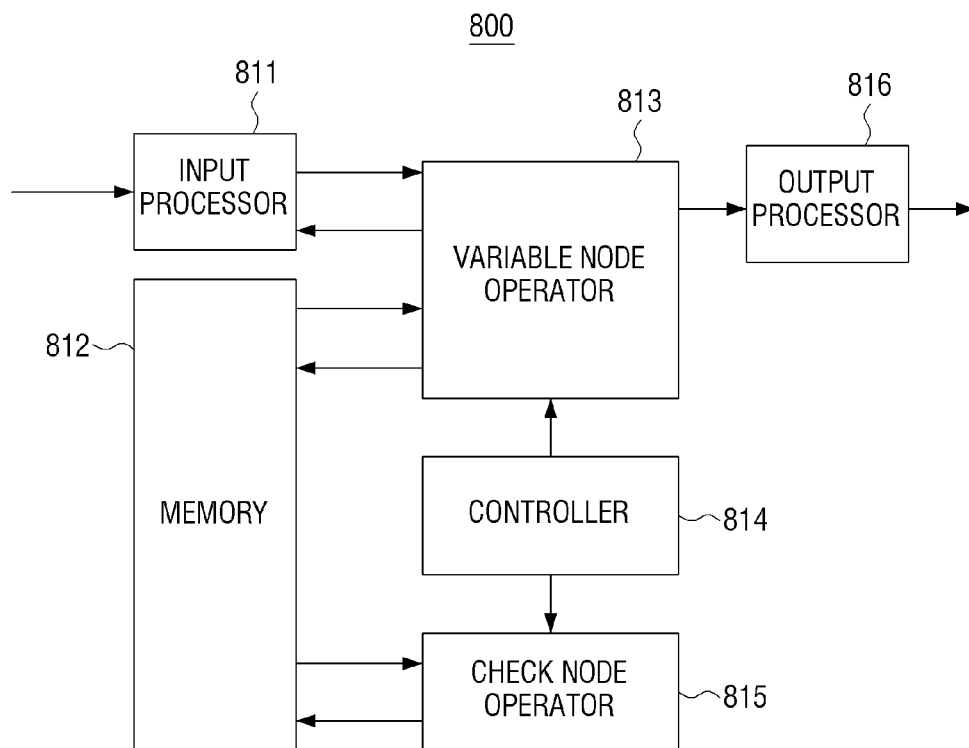


FIG. 9

900

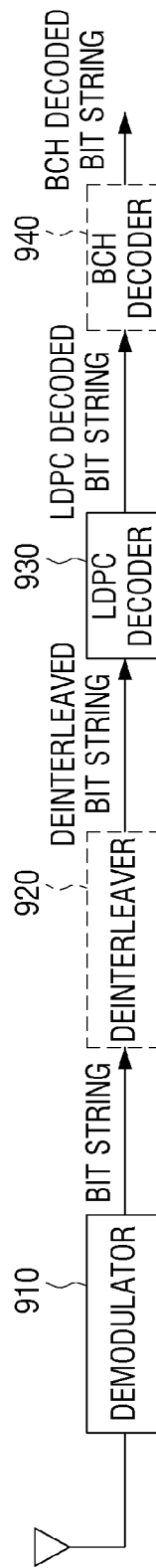


FIG. 10

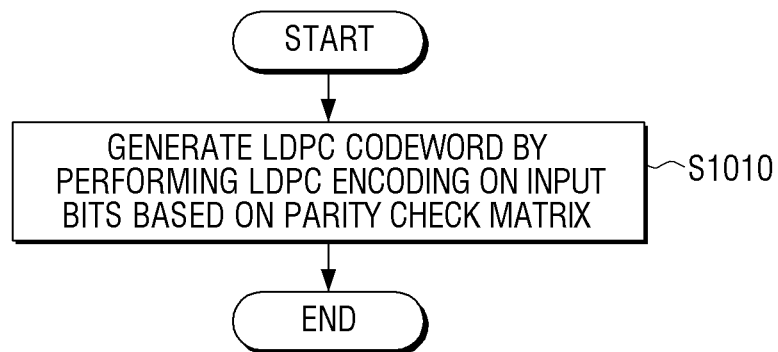
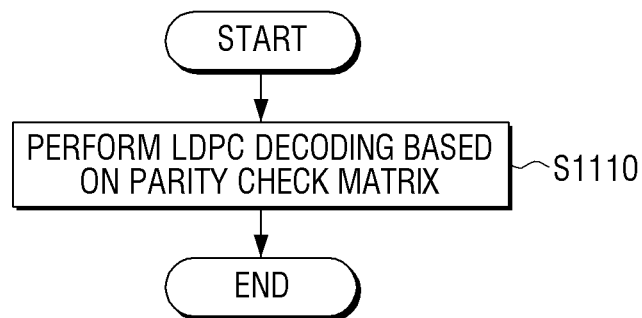


FIG. 11



APPARATUSES AND METHODS FOR ENCODING AND DECODING OF PARITY CHECK CODES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from Korean Patent Application No. 10-2014-0058323, filed on May 15, 2014, in the Korean Intellectual Property Office, and U.S. Provisional Application No. 61/862,633, filed on Aug. 6, 2013, U.S. Provisional Application No. 61/839,080, filed on Jun. 25, 2013, and U.S. Provisional Application No. 61/835,084, filed on Jun. 14, 2013, in the USPTO, the disclosures of which are incorporated herein by reference in their entirety.

BACKGROUND

1. Field

Apparatuses and methods consistent with exemplary embodiments relate to encoding and decoding of parity check codes, and more particularly, to encoding and decoding of parity check codes capable of performing low density parity check (LDPC) encoding and decoding based on a parity check matrix.

2. Description of the Related Art

In a communication/broadcasting system, link performance may be significantly deteriorated due to several types of noise in a channel, a fading phenomenon, and inter-symbol interference (ISI). Therefore, in order to implement high speed digital communication/broadcasting systems requiring a high data throughput and reliability, such as the next generation mobile communication, digital broadcasting and portable Internet, it has been required to develop a technology to address problems occurring from the noise, fading, ISI, etc. Studies on an error correcting code has been recently conducted actively as a method for increasing reliability of communication by efficiently reconstructing distorted information.

In the 1960s, an LDPC code initially introduced by Gallager has been forgotten for a long time due to technological complexity of the LDPC code that could not be implemented by a technology level in those days. However, as a turbo code suggested by Berrou, Glavieux, and Thitimajshima in 1993 shows performance approaching a channel capacity of Shannon, many analyses for performance and features of the turbo code have been conducted. Therefore, many studies on channel encoding based on a graph and iterative decoding have been conducted. As a result, the LDPC code was again studied in the latter half of the 1990s, such that it has been revealed that the performance approaches the channel capacity of the Shannon when decoding is performed by applying iterative decoding based on a sum-product algorithm on a Tanner graph corresponding to the LDPC code.

The LDPC code is generally defined as a parity check matrix and may be represented by a bipartite graph commonly called a Tanner graph.

Hereinafter, a systematic LDPC codeword will be described with reference to FIG. 1. The LDPC codes are LDPC encoded by receiving an information word **102** formed of K_{ldpc} bits or symbols to generate a codeword **100** formed of N_{ldpc} bits or symbols. Hereinafter, for convenience of explanation, it is assumed that the codeword **100** formed of N_{ldpc} bits is generated by receiving the information word **102** including K_{ldpc} bits. That is, when the information word $I=[i_0, i_1, i_2, \dots, i_{K_{ldpc}-1}]$ **102** which is formed of K_{ldpc} input bits is LDPC encoded, the codeword $c=[c_0, c_1, c_2, c_3, \dots, c_{N_{ldpc}-1}]$

100 is generated. That is, the codeword is a bit string formed of a plurality of bits and the bits of the codeword represent each bit forming the codeword. Further, the information word is a bit string formed of a plurality of bits and the bits of the information word represent each bit forming the information word. In this case, in the case of a systematic code, the codeword is formed of $C=[c_0, c_1, c_2, \dots, c_{N_{ldpc}-1}]=[i_0, i_1, i_2, \dots, i_{K_{ldpc}-1}, p_0, p_1, p_2, \dots, p_{N_{ldpc}-K_{ldpc}-1}]$. Here, $P=[p_0, p_1, p_2, \dots, p_{N_{ldpc}-K_{ldpc}-1}]$ is a parity **104** and the number N_{parity} of parity bits is as follows. $N_{parity}=N_{ldpc}-K_{ldpc}$.

The LDPC codes are a kind of linear block codes and include a process of determining a codeword satisfying conditions of following mathematical expression 1.

$$H \cdot c^T = [h_0 h_1 h_2 \dots h_{N_{ldpc}-1}] \cdot c^T = \sum_{i=0}^{N_{ldpc}-1} c_i \cdot h_i = 0, \quad (1)$$

where

$$c = [c_0, c_1, c_2, \dots, c_{N_{ldpc}-1}].$$

In mathematical expression 1 above, H represents the parity-check matrix, C represents the codeword, c_i represents an i-th bit of the codeword, and N_{ldpc} represents a codeword length. Here, h_i represents an i-th column of the parity-check matrix H.

The parity-check matrix H is formed of the same N_{ldpc} columns as the number of bits of the LDPC codeword. The mathematical expression 1 represents that since a sum of a product of the i-th column h_i of the parity-check matrix and the i-th bit c_i of the codeword becomes "0", the i-th column h_i has a relationship with the i-th bit c_i of the codeword.

Meanwhile, the performance of the LDPC codes may be determined according to the parity-check matrix. Therefore, there is a need to design the parity-check matrix for the LDPC codes having improved performance.

SUMMARY

One or more exemplary embodiments of the inventive concept may overcome the above disadvantages and other disadvantages not described above. However, these embodiments are not required to overcome the disadvantages and any of the problems described above.

One or more exemplary embodiments provide apparatuses and methods for encoding and decoding of parity check codes capable of improving LDPC encoding and decoding performance.

According to an aspect of an exemplary embodiment, there is provided an encoding apparatus for performing low density parity check (LDPC) encoding which may include: an LDPC encoder configured to generate an LDPC codeword formed of 16200 bits by performing LDPC encoding based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, the information word sub-matrix being formed of a plurality of column groups each including 360 columns and being defined as a table indicating a position of one (1) present in each 360-th column.

The LDPC encoder may perform the LDPC encoding using a parity check matrix defined as a table such as Table 6 when a code rate of an LDPC code is 7/15.

The LDPC encoder may perform the LDPC encoding using a parity check matrix defined as a table such as Table 10 when the code rate is 5/15.

3

The LDPC encoder may perform the LDPC encoding using a parity check matrix defined as a table such as Table 11 when the code rate is 9/15.

The LDPC encoder may perform the LDPC encoding using a parity check matrix defined as a table such as Table 13 when the code rate is 11/15.

The LDPC encoder may perform the LDPC encoding using a parity check matrix defined as a table such as Table 14 when the code rate is 13/15.

According to an aspect of another exemplary embodiment, there is provided an encoding method for performing LDPC encoding which may include: generating an LDPC codeword formed of 16200 bits by performing the LDPC encoding on input bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and the information word sub-matrix has a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column.

In the generating the LDPC codeword, the LDPC encoding may be performed using a parity check matrix defined as a table such as Table 6 when the code rate is 7/15.

In the generating the LDPC codeword, the LDPC encoding may be performed using a parity check matrix defined as a table such as Table 10 when the code rate is 5/15.

In the generating the LDPC codeword, the LDPC encoding may be performed using a parity check matrix defined as a table such as Table 11 when the code rate is 9/15.

In the generating the LDPC codeword, the LDPC encoding may be performed using a parity check matrix defined as a table such as Table 13 when the code rate is 11/15.

In the generating the LDPC codeword, the LDPC encoding may be performed using a parity check matrix defined as a table such as Table 14 when the code rate is 13/15.

According to an aspect of still another exemplary embodiment, there is provided a decoding apparatus for performing LDPC decoding which may include: an LDPC decoder configured to perform the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and wherein the information word sub-matrix has a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column.

The LDPC decoder may perform the LDPC decoding using a parity check matrix defined as a table such as Table 6 when the code rate is 7/15.

The LDPC decoder may perform the LDPC decoding using a parity check matrix defined as a table such as Table 10 when the code rate is 5/15.

The LDPC decoder may perform the LDPC decoding using a parity check matrix defined as a table such as Table 11 when the code rate is 9/15.

The LDPC decoder may perform the LDPC decoding using a parity check matrix defined as a table such as Table 14 when the code rate is 11/15.

The LDPC decoder may perform the LDPC decoding using a parity check matrix defined as a table such as Table 14 when the code rate is 13/15.

According to yet still another aspect of the present invention, a decoding method for performing LDPC decoding includes: performing the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and wherein the information word sub-matrix comprises a plurality of column groups

4

each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column.

In the performing of the LDPC decoding, the LDPC decoding may be performed using a parity check matrix defined as a table such as Table 6 when the code rate is 7/15.

In the performing of the LDPC decoding, the LDPC decoding may be performed using a parity check matrix defined as a table such as Table 10 when the code rate is 5/15.

In the performing of the LDPC decoding, the LDPC decoding may be performed using a parity check matrix defined as a table such as Table 11 when the code rate is 9/15.

In the performing of the LDPC decoding, the LDPC decoding may be performed using a parity check matrix defined as a table such as Table 13 when the code rate is 11/15.

In the performing of the LDPC decoding, the LDPC decoding may be performed using a parity check matrix defined as a table such as Table 14 when the code rate is 13/15.

Additional and/or other aspects and advantages of the exemplary embodiments will be set forth in part in the description which follows and, in part, will be obvious from the description, or may be learned by practice of these embodiments.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

The above and/or other aspects of the inventive concept will be more apparent by describing certain exemplary embodiments with reference to the accompanying drawings, in which:

FIG. 1 is a diagram showing a codeword of a systematic low density parity check (LDPC) code;

FIG. 2 is a diagram showing a parity check matrix and a factor graph of a general (8, 2, 4) LDPC code;

FIG. 3 is a diagram showing a parity check matrix according to an exemplary embodiment;

FIGS. 4A and 4B illustrate a check node and a variable node used for LDPC decoding, according to exemplary embodiments;

FIG. 5 is a block diagram for describing a configuration of an encoding apparatus according to an exemplary embodiment;

FIG. 6 is a block diagram for describing a configuration of a transmitting apparatus according to an exemplary embodiment;

FIG. 7 is a block diagram for describing a configuration of a decoding apparatus according to an exemplary embodiment;

FIG. 8 is a block diagram for describing a decoding apparatus according to an exemplary embodiment;

FIG. 9 is a block diagram for describing a configuration of a receiving apparatus according to an exemplary embodiment;

FIG. 10 is a flow chart for describing an encoding method according to an exemplary embodiment; and

FIG. 11 is a flow chart for describing a decoding method according to an exemplary embodiment.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

Hereinafter, exemplary embodiments will be described in detail with reference to the accompanying drawings. Further, when it is determined that the detailed descriptions of the known function or configuration related to the exemplary embodiments may obscure the gist of the inventive concept, the detailed descriptions thereof will be omitted.

Hereinafter, low density parity check (LDPC) encoding and decoding technologies in a communication/broadcasting system according to exemplary embodiments will be described.

In the following exemplary embodiments, terms and names defined in the Digital Video Broadcasting the Second Generation Terrestrial (DVB-T2) system, which is one of the European digital broadcasting standards, and a North America digital broadcasting standard system (Advanced Television Systems Committee (ATSC) 3.0) will be used. However, the inventive concept is not limited to these terms and names, but may be similarly applied to other systems.

A graph representation method of an LDPC code will be described with reference to FIG. 2.

FIG. 2 is a diagram showing an example of a parity check matrix H_1 of an LDPC code configured of four (4) rows and eight (8) columns and a Tanner graph thereof. Referring to FIG. 2, since the parity check matrix H_1 has eight (8) columns, it generates a codeword having a length of eight (8), a code generated through H_1 means an LDPC code, and each column corresponds to encoded eight (8) bits.

Referring to FIG. 2, a Tanner graph of the LDPC code encoded and decoded based on the parity check matrix H_1 is configured of eight (8) variable nodes, that is, x_1 (202), x_2 (204), x_3 (206), x_4 (208), x_5 (210), x_6 (212), x_7 (214) and x_8 (216) and four (4) check nodes 218, 220, 222 and 224. Here, an i -th column and a j -th row of the parity check matrix H_1 of the LDPC code correspond to a variable node x_i and a j -th check node, respectively. In addition, the meaning of a value one (1) (that is, a value that is not zero (0)) of a point at which a j -th column and j -th row of the parity check matrix H_1 of the LDPC code intersect with each other is that an edge connecting the variable node x_i and the j -th check node to each other is present on the Tanner graph as shown in FIG. 2.

Degrees of variable nodes and check nodes in the Tanner graph of the LDPC code mean the number of edges connected to the respective nodes, which is the number of entries that are not zero (0) in a column or a row corresponding to a corresponding node in the parity check matrix of the LDPC code. For example, in FIG. 2, degrees of the variable nodes x_1 (202), x_2 (204), x_3 (206), x_4 (208), x_5 (210), x_6 (212), x_7 (214) and x_8 (216) are sequentially 4, 3, 3, 3, 2, 2, 2 and 2, respectively, and degrees of the check nodes 218, 220, 222 and 224 are sequentially 6, 5, 5 and 5, respectively. In addition, the numbers of entries that are not zero (0) in the respective columns of the parity check matrix H_1 of FIG. 2 corresponding to the variable nodes of FIG. 2 sequentially coincide with the above-mentioned degrees 4, 3, 3, 3, 2, 2, 2 and 2, and the numbers of entries that are not zero (0) in the respective rows of the parity check matrix H_1 of FIG. 2 corresponding to the check nodes of FIG. 2 sequentially coincide with the above-mentioned degrees 6, 5, 5 and 5.

As described above, an i -th bit c_i of the LDPC codeword is associated with an i -th column of the parity check matrix and corresponds to an i -th variable node of the Tanner graph. Therefore, performance of the i -th bit may be determined depending on positions and the number of ones (1s) in the i -th column of the parity check matrix. Therefore, performance of N_{ldpc} codeword bits of the codeword depends on the positions and the number of ones (1s) in the parity check matrix.

Hereinafter, a feature of a parity check matrix of an LDPC code having a specific structure will be described with reference to FIG. 3.

According to an exemplary embodiment, a parity check matrix having a structure as shown in FIG. 3 will be considered. The parity check matrix shown in FIG. 3 has a systematic structure in which a codeword includes an information

word as it is. Hereinafter, although the inventive concept will be described based on a parity check matrix of FIG. 3, an applicable range of the inventive concept is not limited to the parity check matrix as shown in FIG. 3.

In FIG. 3, N_{ldpc} means a length of an LDPC codeword, and K_{ldpc} means a length of an information word. The length of the codeword or the information word means the number of bits included in the codeword or the information word. M is an interval at which patterns of columns in a sub-matrix 310 (hereinafter, referred to as an information word sub-matrix) corresponding to the information word are repeated, and Q_{ldpc} is a magnitude at which each column in the information word sub-matrix 310 is cyclically shifted. Values of the integers M and Q_{ldpc} are determined to satisfy an equation: $Q_{ldpc} = (N_{ldpc} - K_{ldpc})/M$. Here, K_{ldpc}/M is also an integer. Values of M and Q_{ldpc} may be changed depending on a length and a code rate (or coding rate) of the codeword.

Referring to FIG. 3, the parity check matrix 300 is divided into the information word sub-matrix 310 and a sub-matrix 320 (hereinafter, referred to as a parity sub-matrix) corresponding to a parity. The information word sub-matrix 310 includes K_{ldpc} columns, and the parity sub-matrix 320 includes $N_{parity} = N_{ldpc} - K_{ldpc}$ columns. The number of rows of the parity check matrix 300 is the same as that ($N_{ldpc} - K_{ldpc}$) of columns of the parity sub-matrix 320.

In the parity sub-matrix 320 including a K_{ldpc} -th column to an $N_{ldpc}-1$ -th column of the parity check matrix 300, positions of entries having a weight-1, that is, a value of one (1), have a dual diagonal structure. Therefore, all of degrees (here, the degree is the number of ones (1s) included in each column) of columns other than the ($N_{ldpc}-1$)-th column among columns included in the parity sub-matrix 320 are two (2), and a degree of the ($N_{ldpc}-1$)-th column is one (1).

Referring to FIG. 3, a structure of the information word sub-matrix 310, that is, a sub-matrix including a zero (0)-th column to a ($K_{ldpc}-1$)-th column, in the parity check matrix 300 follows the following rules.

First, K_{ldpc} columns corresponding to the information word in the parity check matrix 300 belong to a plurality of column groups or blocks each having M columns, and are divided into a total of K_{ldpc}/M column groups. Columns belonging to the same column group have a relationship in which they are shifted from a previous column by Q_{ldpc} .

Second, when it is assumed that a degree of a zero (0)-th column of an i -th ($i=0, 1, \dots, K_{ldpc}/M-1$) column group is D_i and positions of the respective rows at which one (1) is present are $R_{i,0}^{(0)}, R_{i,0}^{(1)}, \dots, R_{i,0}^{(D_i-1)}$, an index $R_{i,j}^{(k)}$ of a row at which a weight-1 is positioned in a j -th column within the i -th column group is determined as represented by following mathematical expression 2.

$$R_{i,j}^{(k)} = (R_{i,j-1}^{(k)} + Q_{ldpc}) \bmod (N_{ldpc} - K_{ldpc}) \quad (2),$$

where $k=0, 1, 2, \dots, D_i-1$, $i=0, 1, \dots, K_{ldpc}/M-1$, and $j=1, 2, \dots, M-1$.

Meanwhile, above mathematical expression 2 may be represented by the following mathematical expression 3.

$$R_{i,j}^{(k)} = \{R_{i,0}^{(k)} + (j \bmod M) \times Q_{ldpc}\} \bmod (N_{ldpc} - K_{ldpc}) \quad (3),$$

where $k=0, 1, 2, \dots, D_i-1$, $i=0, 1, \dots, K_{ldpc}/M-1$, and $j=1, 2, \dots, M-1$.

In the above mathematical expressions, $R_{i,j}^{(k)}$ means an index of a row at which a k -th weight-1 is present in the j -th column within the i -th column group, N_{ldpc} means a length of the LDPC codeword, K_{ldpc} means a length of the information word, D_i means a degree of columns belonging to the i -th column group, and M means the number of columns belonging to one column group.

According to these mathematical expressions, when only a value of $R_{i,0}^{(k)}$ is recognized, an index of a row at which the k-th weight-1 is present within the i-th column group may be recognized. Therefore, when an index values of a row at which the k-th weight-1 is present in a zero (0)-th column within each column group is stored, positions of a column and a row at which the weight-1 is present in the parity check matrix **300** (that is, the information word sub-matrix **310** of the parity check matrix **300**) having the structure shown in FIG. 3 may be recognized.

According to the above-mentioned rules, all of the degrees of the columns belonging to the i-th column group are the same D_i . Meanwhile, according to the above-mentioned rules, the LDPC code in which information on the parity check matrix **300** is stored may be simply represented as follows.

As a specific example, in the case in which N_{ldpc} is 30, K_{ldpc} is 15, and Q_{ldpc} is three (3), information on positions of rows at which the weight-1 is positioned in zero (0)-th columns within three column groups may be represented by sequences as represented by following mathematical expression 4. The sequences as represented by following mathematical expression 4 may be called a weight-1 position sequence.

$$\begin{aligned} R_{1,0}^{(1)}=1, R_{1,0}^{(2)}=2, R_{1,0}^{(3)}=8, R_{1,0}^{(4)}=10, \\ R_{2,0}^{(1)}=0, R_{2,0}^{(2)}=9, R_{2,0}^{(3)}=13, \\ R_{3,0}^{(1)}=0, R_{3,0}^{(2)}=14. \end{aligned} \quad (4)$$

In above mathematical expression 4, $R_{i,j}^{(k)}$ means an index of a row at which the k-th weight-1 is present in the j-th column within the i-th column group.

The weight-1 position sequences as represented by above mathematical expression 4, which indicates indices of the rows at which one (1) is positioned in the zero (0)-th columns of the respective column groups, may be more simply represented by following Table 1.

TABLE 1

1 2 8 10
0 9 13
0 14

In Table 1 showing positions of entries having a weight-1, that is, a value of one (1), in the parity check matrix, an i-th weight-1 position sequence may be represented by indices of rows at which the weight-1 is present in the zero (0)-th column belonging to the i-th column group.

The LDPC code suggested in the present embodiment is characterized in that it is grouped in a unit of M columns in the parity check matrix as described above to have a specific form. One column group configured of M columns in the parity check matrix **300** corresponds to an information bit group **340** of the information word in the codeword **330** of FIG. 3 having M bits. In other words, a term 'column group' used in the present embodiment means that grouping was performed on the parity check matrix, and a term 'bit group' means that grouping was performed on the codeword. In addition, it is to be noted that the column group and the bit group have a one-to-one corresponding relationship therebetween.

Performance of the LDPC code may be changed depending on the positions and the number of the weight-1s configuring the parity check matrix. In other words, when it is assumed that a size of the parity check matrix is determined for a given codeword length, a code rate, and the like, the performance of the LDPC code may be changed depending on the positions

and the number of the weight-1s configuring the parity check matrix. In addition, the number of weight-1s is closely related to complexity of encoding and decoding of the LDPC code.

Therefore, in the case in which the size of a parity check matrix is determined for a given codeword length, code rate, and the like, it is an important process in designing an excellent LDPC code to appropriately determine the number and the positions of weight-1s.

In the present embodiment, a design method of an LDPC code grouped in a unit of M columns as shown in FIG. 3 is suggested, and encoding and decoding apparatuses using the LDPC code designed by this method are suggested.

The following conceptually and sequentially shows a process for a design method of an LDPC code according to an exemplary embodiment.

Step 1) a size (N_{ldpc} , K_{ldpc}) of a parity check matrix to be designed and a value of M (or Q_{ldpc}) are determined. It means that the parity check matrix is configured of N_{ldpc} columns and $N_{ldpc}-K_{ldpc}$ rows. In addition, it is to be noted that a structure of the parity check matrix to be designed should be the same as that of the parity check matrix **300** of FIG. 3. For example, the parity check matrix has a staircase structure in which degrees of $N_{ldpc}-K_{ldpc}-1$ columns are two (2) and a degree of one column is one (1), as in the parity sub-matrix **320** of the parity check matrix **300** of FIG. 3.

Step 2) a size and a structure of a mother matrix (or mother parity check matrix) for designing the parity check matrix having the size determined in Step 1 are set. A size of the mother matrix is configured of N_{ldpc}/M columns and $(N_{ldpc}-K_{ldpc})/M$ rows, and a parity portion has the same structure as that of the parity check matrix **300** of FIG. 3. That is, the parity portion has a staircase structure in which degrees of $N_{ldpc}-K_{ldpc}-1$ columns are two (2) and a degree of one column is one (1), as in the parity sub-matrix **320** of the parity check matrix **300** of FIG. 3.

Step 3) an appropriate degree distribution is found in order to design the mother matrix. As a typical method for finding the degree distribution, density evolution (reference: Richardson, T., and URBANKE, R.: 'The capacity of low-density parity-check codes under message-passing decoding', IEEE Trans. Inf. Theory, 2001, 47, (2), pp. 599-618) may be used. When the degree distribution is found, it is to be noted that the number of columns having a degree of two (2) is fixed to $(N_{ldpc}-K_{ldpc})/M-1$ and the number of columns having a degree of one (1) is fixed to one (1).

Step 4) the mother matrix is designed so as to satisfy the degree distribution found in Step 3. The mother matrix is designed in consideration of cycle characteristics in an order of low degrees.

Step 5) a final parity check matrix is designed from the mother matrix. As a method of designing the final parity check matrix, a lifting method in which the cycle characteristics are considered from the mother matrix is used.

Hereinafter, the lifting method described in Step 5 will be described in more detail.

The lifting method is a method that may relatively simply generate a parity check matrix having a larger size based on a parity check matrix having a small size. For example, when a parity check matrix H_1 including column groups configured in a unit of M_1 columns and having a total number of columns corresponding to N_1 and the number of rows corresponding to N_1-K_1 is given, a parity check matrix H_2 including column groups configured in a unit of M_2 columns and having a total number of columns corresponding to N_2 and the number of rows corresponding to N_2-K_2 may be obtained by the lifting method.

Here, the following relationship: $N_2/N_1=(N_2-K_2)/(N_1-K_1)=M_2/M_1=A$ (A indicates a positive integer larger than one (1)) is satisfied. Here, it is to be noted that $Q_{ldpc1}=(N_1-K_1)/M_1=(N_2-K_2)/M_2=Q_{ldpc2}$.

Hereinafter, a process of generating the parity check matrix H_2 larger than the given parity check matrix H_1 from the parity check matrix H_1 by applying the lifting while maintaining the structure of FIG. 3 will be described.

It is assumed that a sequence indicating information on an i -th column group corresponding to an information word bit of the given parity check matrix H_1 is $R_{i,0}^{(0)}, R_{i,0}^{(1)}, \dots, R_{i,0}^{(D_i-1)}$ in order to describe the lifting process. Here, $i=0, 1, \dots, K_1/M_1-1$, and D_i means a degree of columns belonging to the i -th column group.

Lifting Step 1) a matrix having the same structure as that of a sub-matrix corresponding to the parity portion of FIG. 3 and having a size of $(N_2-K_2) \times (N_2-K_2)$ is set to a parity sub-matrix corresponding to a parity portion of H_2 .

Step 2) i is initialized to zero (0).

Step 3) for each of sequences $R_{i,0}^{(k)}$ ($k=0, 1, 2, \dots, D_i-1$) indicating the information on the i -th column group corresponding to the information word bit of the parity check matrix H_1 , a set $B_i^{(k)}=\{R_{i,0}^{(k)}, R_{i,0}^{(k)}+(N_1-K_1), \dots, R_{i,0}^{(k)}+(A-1) \times (N_1-K_1)\}$ configured of A sequences is defined as follows. Here, A is a positive integer satisfying $N_2/N_1=(N_2-K_2)/(N_1-K_1)=M_2/M_1=A$.

Step 4) sequences $S_{i,0}^{(k)}$ ($k=0, 1, 2, \dots, D_i-1$) satisfying following <condition 1> and <condition 2> are sequentially found on an assumption that information word column groups corresponding to an $(i+1)$ -th column group to an $(N_2-K_2)/M_2-1$ -th column group are not present for the parity check matrix H_2 to be designed.)

<Condition 1>: $S_{i,0}^{(k)} \in B_i^{(k)}$ ($k=0, 1, 2, \dots, D_i-1$)

<Condition 2>: a sequence in which a value of a girth on a Tanner graph is maximum and the number of cycles having a corresponding girth is minimum among sequences satisfying <Condition 1>. Here, the girth means a length of the shortest cycle among cycles present on the Tanner graph. However, when the best cases are several, one of them is arbitrarily selected.

Step 5) processes of Step 3 and Step 4 are continuously repeated for $i=1, 2, \dots, (N_2-K_2)/M_2-1$.

Step 6) a finally selected sequence $S_{i,0}^{(k)}$ ($i=0, 1, \dots, K_{ldpc}/M-1, k=0, 1, 2, \dots, D_i-1$) is determined to be a sequence indicating a column group corresponding to an information word bit of H_2 .

When the lifting method as described above is used, it may become relatively simple to design a parity check matrix configured of N_{ldpc} columns and $N_{ldpc}-K_{ldpc}$ rows and including a parity portion having the same structure as that of the parity check matrix 300 of FIG. 3 from a mother parity check matrix configured of N_{ldpc}/M columns and $(N_{ldpc}-K_{ldpc})/M$ rows and including a parity portion having the same structure as that of the parity check matrix 300 of FIG. 3.

When a parity check matrix is to be designed by applying the lifting for the given mother parity check matrix once, since the numbers of columns and rows of the mother matrix are $1/M$ of the size of the parity check matrix that is to be finally designed, respectively, a total number of selections of the respective figures $S_{i,0}^{(k)}$ configuring a sequence that is to be found in the lifting process is M . As described above, when the M selections for all of the respective figures indicating the column group corresponding to the information word bit are present, a design is not easy due to an excessive many number when M is relatively large.

However, in the case in which a parity check matrix is designed by applying the lifting in several steps for the given

mother matrix, the parity check matrix may be more easily designed. For example, when the mother parity check matrix is H_1 and the parity check matrix that is to be finally designed is H , assume that the lifting was designed through w steps such as $H_1 \rightarrow H_2 \rightarrow \dots H_w \rightarrow H$.

Here, when a size of the column group configuring each parity check matrix H_i is M_i , it may be appreciated that the following relationship: $M_2=A_1 \times M_1, M_3=A_2 \times M_2, \dots, M_w=A_{(w-1)} \times M_{(w-1)}, M=A_w \times M_w$ is satisfied by the assumption of the lifting process. Here, A_i is a positive integer larger than 1 ($i=1, 2, \dots, w$). In addition, when the above Equation is arranged, it may be easily confirmed that $M=M_1 \times A_1 \times A_2 \times \dots \times A_w$.

In summary, since the number of selections of the respective figures of a sequence indicating the column group of the information word bit in each i -th lifting process is A_i , it may be appreciated that when the lifting is applied w times in order to design H from H_1 , a total number of selections is $(A_1 + A_2 + \dots + A_w)$. This is significantly decreased as compared with the M selections, that is, $A_1 \times A_2 \times \dots \times A_w$ selections when the lifting is applied only once. It may be appreciated that the more the lifting applying steps, the more efficient.

However, in the case in which excessively many lifting steps are applied, the number of selections is excessively decreased, such that it is difficult to find a sequence of column groups having good cycle characteristics. Therefore, the lifting steps may be appropriately selected depending on a code that is to be designed.

As an example of a design result by the above-mentioned method, in the case in which a length N_{ldpc} of the codeword is 16200, a code rate is $7/15$, and M is 360 (or $Q_{ldpc}=24$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i -th column group of the parity check matrix having the structure of FIG. 3 are shown by following Table 2.

TABLE 1

Indices of rows at which 1s are positioned	
i	in 0-th column of i -th column group
0	235 1639 1674 1780 1834 2149 2365 2402 2852 2923 3560 3782 3841 4710 4764 4798 5313 6568 6624 7451 7773 8007 8379 8519
1	446 837 968 975 1005 1747 1986 2026 2908 2982 3099 3780 4097 4513 5577 6290 6637 7159 7796 8016 8093 8104 8363 8567
2	360 491 1264 1685 1734 1890 2479 3897 4102 4653 4660 4849 5570 6531 6551 6667 6831 7160 7286 7525 7860 7918 8170 8321
3	188 344 950 997 1152 2766 3442 3819 3863 4425 5105 5258 5401 5514 5662 5703 5877 6496 6604 6851 7020 7327 8203 8621
4	1373 2412 6145 7700
5	1909 5421 7470 7530
6	3849 6939 7409 8503
7	1730 3575 6280 8572
8	876 1090 4430 8834
9	1223 2971 3776 4993
10	1772 2799 3336 3555
11	2782 3442 3569 4251
12	437 2465 3203
13	1992 6512 8466
14	4563 5635 6206
15	1719 2974 6991
16	3573 4212 5834
17	2991 7153 7282
18	1391 3451 5585
19	584 5612 7552
20	220 558 8121

As another example, in the case in which a length N_{ldpc} of the codeword is 16200, a code rate is $9/15$, and M is 360 (or $Q_{ldpc}=18$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i -th column group of the parity check matrix having the structure of FIG. 3 are shown by following Table 3.

11

TABLE 3

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	5 144 500 526 928 1110 2279 3336 3673 4045 4148 4175 4372 4815 4953 5557 5960 6181
1	453 835 1010 2422 2827 2879 2912 3017 3670 3713 3933 3936 4119 4747 4758 5948 6174 6340
2	368 725 775 1050 1215 1281 1414 1665 2218 3746 3975 4259 4517 4777 4873 4878 5432 5506
3	10 563 716 934 951 1555 1866 1970 2379 2454 2614 3073 3467 3491 4680 5924 5931 6049
4	317 415 501 1188 1705 2036 2140 2926 2964 3624 3693 3914 4111 4864 5337 5723 6810 6179
5	3 332 499 525 698 1387 1398 1642 1951 2411 2594 2656 2741 2934 3143 3363 5640 5650
6	533 2108 5649
7	2664 5143 5821
8	2195 3155 5644
9	57 4454 4733
10	1958 5023 6255
12	400 2930 3215
12	1302 5307 6353
13	2748 3735 4074
14	3598 4144 5433
15	641 1592 4537
16	1661 3847 5024
17	2862 3249 5667
18	1992 2685 3358
19	426 4768 6391
20	2636 4540 5559
21	1288 4616 5550
22	3913 5042 5517
23	13 2656 4087
24	356 1344 5870
25	5729 6172 6300
26	1816 3361 6177

As still another example, in the case in which a length N_{ldpc} of the codeword is 16200, a code rate is 11/15, and M is 360 (or $Q_{ldpc}=12$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by following Table 4.

TABLE 4

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	411 499 536 726 1094 1341 1499 2053 2314 2753 3340 4245
1	333 582 638 1907 2392 2964 3034 3397 3735 4013 4148 4159
2	258 419 1308 1312 2331 3091 3104 3266 3437 3637 3837 3922
3	40 379 531 764 969 1634 2473 3384 3449 3982 4170 4295
4	66 316 319 350 365 1750 2325 2696 3061 3231 3492 3887
5	83 158 1300 1971 2191 2898 2904 3106 3509 3596 3633 4165
6	54 131 595 2120 2320 2833 3021 3039 3142 3900 4154 4241
7	218 1601 3167
8	868 1477 4004
9	859 1380 2571
10	1495 3429 4145
11	1266 2146 3026
12	1704 2768 3473
13	1732 2303 4170
14	1790 2168 3298
15	909 1451 3495
16	777 2490 4118
17	1354 2659 3700
18	1107 2720 4014
19	977 3096 3678
20	621 673 1832

12

TABLE 4-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
5	21 2959 3855 3963
	22 802 2103 3204
	23 1730 2836 4080
	24 1405 1931 2323
	25 1565 1845 3127
	26 1400 1891 2556
10	27 344 827 2937
	28 1107 1720 2577
	29 1871 2692 4155
	30 2301 3576 3866
	31 1948 3157 3766
	32 1560 3570 4153

As yet still another example, in the case in which a length N_{ldpc} of the codeword is 16200, a code rate is 13/15, and M is 360 (or $Q_{ldpc}=6$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by following Table 5.

TABLE 5

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
25	0 380 671 699 745 1410 1564
	1 173 232 849 1063 1242 1454
	2 247 328 1778 2040 2051 2151
30	3 40 1064 1321 1392 1583 2121
	4 139 508 999 1032 1550 2141
	5 21 292 386 631 939 1290
	6 510 530 679 885 1054 2093
	7 929 998 1092 1264 1773 2119
	8 127 299 597 1064 1782 1966
35	9 167 228 483 1159 2030 2110
	10 44 517 797 1000 1197 1980
	11 444 477 700 782 1303 1733
	12 893 1305 2030
	13 599 696 2121
	14 58 474 865
40	15 1055 1450 1850
	16 1099 1313 1418
	17 860 1206 2002
	18 1249 1346 2085
	19 35 1384 2106
	20 1084 1245 1933
	21 19 974 1469
45	22 679 1230 1360
	23 916 1083 2130
	24 332 1536 1839
	25 499 700 1820
	26 1127 1332 1777
50	27 992 1785 1979
	28 142 169 1707
	29 971 1255 1296
	30 149 579 1484
	31 448 813 2034
	32 107 909 1703
55	33 178 1322 2053
	34 323 1428 1816
	35 89 783 1285
	36 1550 1881 2034
	37 239 1492 1578
	38 654 702 1747

Meanwhile, in the design process of an LDPC code, in Step 5), the lifting method in which the cycle characteristics are considered was applied. When various algebraic characteristics as well as the cycle characteristics are additionally considered, a code having better performance may be designed.

Generally, since the performance of an LDPC code has an influence on the degree distribution as well as the cycle char-

13

acteristics, a code having better performance may be designed in consideration of both of these two characteristics.

In the present embodiment, a method applied to a process of determining a parameter depending on cycles having the shortest length and the number of variable nodes included in these cycles and having a specific degree and determining the sequence in Lift Step 4) depending on a rule determined through the parameter is suggested.

As an example of the present embodiment, <Condition 2> of the Lifting Step 4) is changed into <Condition 2'> and <Condition 3>.

<Condition 2'>: a sequence in which a girth is maximum for cycles satisfying the following <Condition 3> and the number of cycles having the corresponding girth value is minimum among sequences satisfying <Condition 1>.

<Condition 3>: cycles considered in the case in which the lifting process is applied to column groups having degrees of A and B are as follows:

cycles in which the number of variable nodes having a degree of A among variable nodes included in the cycles in a process of performing lifting of a column group having a degree of A is x_1 or less, and

cycles in which a value of (the number of variable nodes having a degree of A+the number of variable nodes having a degree of B×C) for variable nodes included in the cycles in a process of performing lifting of a column group having a degree of B is x_2 or less.

However, all cycles are considered in the case in which the lifting process is applied to column groups of which degrees are not A and B.

Here, A is a positive integer of two (2) or more, B is a positive integer larger than A and smaller than a maximum degree of the parity check matrix, and C, which is a weighting factor, has a positive integer value.

In addition, all cycles are considered without distinction of a specific cycle in the case in which the lifting process is applied to the column groups of which degrees are not A and B.

As a specific example, the case in which A=3, B=4, and C=2 will be described.

For example, in the lifting process, the lifting is performed in consideration of only cycles in which the number of variable nodes (which is the same as that of columns) having a degree of three (3) among variable nodes included in the cycles in a process of performing the lifting of column groups having a degree of three (3) is x_1 or less and (the number of variable nodes having a degree of four (4)+the number of variable nodes having a degree of three (3)) among variable nodes included in the cycles in a process of performing the lifting of column groups having a degree of four (4) is x_2 or less.

Generally, in simple lifting, the parity check matrix is designed such that the number of cycles is decreased. In this process, the parity check matrix is designed such that the number of cycles satisfying the above-mentioned conditions is decreased.

The reason why the above-mentioned conditions have an influence on designing the LDPC code having a better performance is that the cycles and the degree distribution, which have an influence on the LDPC code, have been considered in the above-mentioned conditions.

Examples of an LDPC code designed in consideration of these additional conditions are shown in following Tables 6 to 15.

For reference, (x_1, x_2) considered in Table 6 is (4, 5), (x_1, x_2) considered in Table 7 is (4, 5), (x_1, x_2) considered in Table 8 is (3, 4), and (x_1, x_2) considered in Table 9 is (3, 4).

14

In addition, (x_1, x_2) considered in Table 10 is (5, 5), (x_1, x_2) considered in each of Tables 11 to 13 is (4, 4), and (x_1, x_2) considered in each of Tables 14 and 15 is (3, 4).

Referring to Tables 6 to 15, it may be appreciated that different LDPC codes may be designed for the same x_1 and x_2 values. It is to be noted that the reason is that a plurality of selections are possible in selecting the sequence in the lifting process.

As an example of a design result in consideration of the additional conditions as described above, in the case in which a length N_{ldpc} of the codeword is 16200, a code rate is 7/15, and M is 360 (or $Q_{ldpc}=24$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by following Table 6.

TABLE 6

Indices of rows at which 1s are positioned in	
i	0-th column of i-th column group
0	432 699 893 942 1285 1427 1738 2199 2441 2565 2932 3201 4144 4419 4678 4963 5423 5922 6433 6564 6656 7478 7514 7892
1	220 453 690 826 1116 3425 1488 1901 3119 3182 3568 3800 3953 4071 4782 5038 5555 6836 6871 7131 7609 7850 8317 8443
2	300 454 497 930 1757 2145 2314 2372 2467 2319 3191 3256 3699 3984 4538 4965 5461 5742 5912 6135 6649 7636 8078 8455
3	24 65 565 609 990 1319 1394 1465 1918 1976 2463 2987 3330 3677 4195 4240 4947 5372 6453 6950 7058 8412 8500 8599
4	1373 4668 5324 7777
5	189 3930 5766 6877
6	3 2961 4207 5747
7	1108 4768 6743 7106
8	1282 2274 2750 6204
9	2279 2587 2737 6344
10	2889 3164 7275 8040
11	133 2734 5081 8386
12	437 3203 7121
13	4280 7128 8490
14	619 4563 6206
15	2799 6814 6991
16	244 4232 5925
17	1719 7657 8554
18	53 2895 6685
19	584 5420 6856
20	2958 5834 8103

As another example of the design result in consideration of the additional conditions, in the case in which a length N_{ldpc} of the codeword is 16200, a code rate is 9/15, and M is 360 (or $Q_{ldpc}=18$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by following Table 7.

TABLE 7

Indices of rows at which 1s are positioned in	
i	0-th column of i-th column group
0	692 1041 1719 1963 2149 2318 2562 2740 2821 3358 3581 4188 4412 3033 5058 6033 6161 6478
1	85 158 231 454 942 981 1569 1762 1848 3152 3286 4691 5119 6351 5885 5905 6254 6281
2	44 111 626 857 1244 1381 1401 1912 2694 2934 1178 3627 3679 3941 4469 5128 5406 6373
3	230 646 1245 1848 1889 2111 2179 2583 2756 2988 3589 4353 4688 4744 5712 5908 5935 6329
4	102 845 1103 1471 1788 1883 1928 2311 2898 2967 3112 3483 3806 4712 5041 5176 5349 5674
5	118 263 1040 1835 2259 2472 3104 6760 3837 3869 3906 2843 4119 5081 5119 5222 5332 5520
6	533 2108 5631
7	2264 5557 5821
8	1421 3155 5644

15

TABLE 7-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
9	57 305 4454
10	302 5023 6255
11	400 986 3215
12	1302 1979 6243
13	3735 4074 4998
14	4144 4354 6433
15	541 1592 2773
16	481 1661 5024
17	2862 3249 3667
18	2280 2685 6022
19	426 4768 6391
20	969 7636 4540
21	1288 4616 5550
22	3913 5042 5517
23	13 2656 4087
24	356 3306 5870
25	448 5729 6300
26	517 1816 6177

As still another example of the design result in consideration of the additional conditions, in the case in which a length N_{ldpc} of the codeword is 16200, a code rate is 11/15, and M is 360 (or $Q_{ldpc}=12$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by following Table 8.

TABLE 8

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	191 507 750 1494 1713 1915 2438 2609 2928 3145 3392 3442
1	293 1177 1544 2563 2266 2508 2894 3286 4462 3703 3940 4223
2	530 708 822 3185 1282 1420 1715 2331 2715 2909 3776 3913
3	1168 1391 1424 1501 1557 1966 2227 2310 2940 3134 3219 4217
4	90 140 366 1393 1848 2251 2769 2931 3125 1383 3968 3994
5	378 559 822 1813 2224 2999 2734 3069 3324 3500 3551 4084
6	240 777 1022 1216 2303 2338 2581 2909 3183 3836 4038 4171
7	218 1601 2327
8	584 1204 1477
9	1380 2035 2571
10	1495 3429 4145
11	1878 2194 3025
12	1565 1704 2768
13	508 1643 4170
14	1790 2350 2672
15	791 3297 3495
16	777 2490 4118
17	358 643 1828
18	1107 2768 4014
19	137 1242 3096
20	621 673 1812
21	2609 3855 3961
22	2103 4150 4308
23	1514 2776 4080
24	1405 2323 2819
25	118 2177 3127
26	1400 1891 2558
27	344 1115 2937
28	1107 1720 2577
29	359 2944 4166
30	2301 3575 3866
31	40 1366 3157
32	1560 2574 4153

As yet still another example of the design result in consideration of the additional conditions, in the case in which N_{ldpc} is 16200, a code rate is 13/15, and M is 360 (or $Q_{ldpc}=6$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by the following Table 9.

16

TABLE 9

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
5	0 812 1005 1572 1691 2092 2113
	1 445 488 576 839 1059 1210
	2 166 199 657 1269 1350 1712
	3 162 771 820 1225 1412 1715
	4 224 287 760 1071 1087 1194
	5 64 243 1052 1335 1475 2130
10	6 44 267 307 1433 1632 1774
	7 317 1255 1390 1437 1884 1946
	8 716 774 808 1033 1505 1761
	9 367 402 509 777 1454 1966
	10 43 281 354 1142 1240 2043
	11 65 352 570 705 751 955
15	12 893 903 1082
	13 599 1200 2121
	14 474 646 1729
	15 1055 1408 1850
	16 61 113 1418
	17 730 1206 2138
20	18 811 1346 2085
	19 35 1384 2106
	20 1084 1245 1933
	21 25 974 1469
	22 769 988 1230
	23 358 1341 2130
	24 894 1568 1839
25	25 268 499 1820
	26 811 1127 1332
	27 908 1575 1979
	28 142 169 1707
	29 1255 1298 2003
	30 149 440 529
30	31 448 813 2034
	32 107 1353 1700
	33 178 1322 2053
	34 323 976 1428
	35 89 783 1285
	36 1550 1881 2034
35	37 239 1578 1594
	38 702 1747 1828

As yet still another example of the design result in consideration of the additional conditions, in the case in which N_{ldpc} is 16200, a code rate is 5/15, and M is 360 (or $Q_{ldpc}=30$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by following Table 10.

TABLE 10

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
50	0 245 449 491 980 1084 1194 1277 1671 2026 3185 4399 4900 5283 5413 5558 6370 7492 7768 7867 7984 8306 8483 8636 9357 9642 10045 10179 10261 10338 10412
	1 1318 1584 1682 1880 1954 2000 2062 3387 3441 1879 3931 4240 4302 4445 4503 5117 5588 5675 5793 3955 6097 5221 6449 6615 7218 7394 9535 9896 10009 10763
55	2 105 472 785 911 1168 1450 2550 2832 3277 3624 4128 4460 4372 4669 4783 5102 5133 5199 5905 6647 7028 7086 7703 8121 8217 9149 9304 9475 9736 9384
	3 1217 9338 9737 8334
	4 855 894 2979 9443
	5 7506 7811 9232 9982
	6 848 3313 3880 3990
60	7 2095 4112 4620 9946
	8 1400 2396 6130 7483
	9 1002 2241 7067 10418
	10 2008 3299 7215 7502
	11 1161 7705 8194 8534
	12 2316 4803 8849 9359
	13 125 1860 3277
65	14 1141 8033 9072

17

As yet still another example of the design result in consideration of the additional conditions, in the case in which N_{ldpc} is 16200, a code rate is 9/15, and M is 360 (or $Q_{ldpc}=18$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by following Tables 11 and 12.

TABLE 11

Indices of rows at which 1s are positioned in	
i	0-th column of i-th column group
0	350 462 1291 1383 3821 2239 2493 3328 3353 3772 3872 3923 4259 4426 4542 4972 5347 6217 6246 6332 6386
1	177 869 1214 1253 1398 1482 1737 2014 2161 2331 3108 3297 3438 4388 4480 4456 4522 4783 5273 6037 6395
2	347 501 658 966 1622 1659 1934 2117 2527 3158 3231 3379 3427 3739 4218 4497 4894 5000 5167 5728 5975
3	319 398 599 1143 1796 3198 3521 3686 4139 4453 4556 4636 4688 4753 4986 5199 5224 5496 5698 5724 6123
4	162 257 304 574 945 1695 1855 2527 2780 2902 2958 3439 3484 4224 4759 4928 5156 5303 5971 6158 6477
5	807 1699 2941 4276
6	2652 2857 4680 5358
7	329 2100 2512 3632
8	1151 1231 3872 4869
9	1561 3365 5338 5303
10	407 794 1455
11	3438 5683 5749
12	1504 1985 3563
13	440 5021 6321
14	184 3645 5923
15	1217 1462 6422
16	1212 4715 5973
17	4098 5100 5642
18	5512 5857 6226
19	2583 5506 5933
20	784 1801 4890
21	4734 4779 4875
22	933 5081 5377
23	127 4125 4704
24	1244 2178 3352
25	3659 6360 6465
26	1686 3464 4336

TABLE 12

Indices of rows at which 1s are positioned in	
i	0-th column of i-th column group
0	366 662 741 1053 2010 2487 2551 2627 3190 3490 3515 3590 3704 4160 4757 5041 5501 5569 5778 6004 6424
1	311 350 742 1058 1128 1252 1503 1667 1749 2112 2446 2671 2983 3047 3224 3504 5409 5541 5563 6272 6407
2	565 801 1543 1707 1739 2106 2319 2760 2969 3155 3225 3270 3362 4382 4435 4844 5020 5053 6040 6304 6349
3	79 170 200 1240 1336 1580 1812 2117 2337 2361 2422 2458 3083 4045 4446 4700 4938 5383 6047 6075 6138
4	135 678 797 1312 1801 2431 2461 3032 3350 3383 3654 3820 3881 3921 4164 5007 5248 5336 5612 5747 5857
5	1951 3088 3783 6153
6	798 5278 6046 6259
7	426 815 2552 5670
8	161 3818 5109 5353
9	1183 4151 4742 5815
10	74 2607 3791
11	18 3949 4297
12	359 3191 4798
13	1097 1340 4737
14	1485 5239 6170
15	1264 5447 5594
16	2011 5766 5831
17	102 1050 3320
18	1168 7573 5548
19	1413 2122 4295

18

TABLE 12-continued

Indices of rows at which 1s are positioned in	
i	0-th column of i-th column group
20	1722 3835 3862
21	2007 2088 6189
22	254 805 3443
23	2629 3174 4413
24	1300 3924 4790
25	3351 5216 5441
26	1970 2392 3198

As yet still another example of the design result in consideration of the additional conditions, in the case in which N_{ldpc} is 16200, a code rate is 11/15, and M is 360 (or $Q_{ldpc}=12$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by following Table 13.

TABLE 13

Indices of rows at which 1s are positioned in	
i	0-th column of i-th column group
0	108 297 703 742 1345 1443 1495 1528 1812 2341 2559 2669 2810 2877 3442 3690 3755 3904 4264
1	180 211 477 788 824 1090 1272 1578 1685 1948 2050 2195 2233 2546 2757 2946 3147 3299 3544
2	627 741 1135 1157 1225 1333 1378 1427 1454 1696 1757 1772 2099 2208 2592 3354 3580 4066 4742
3	9 795 959 989 1006 1032 1135 1209 1382 1484 1703 1855 1985 2043 2629 2845 3136 3450 3742
4	230 413 801 829 1108 1170 1291 1759 1793 1827 1976 2000 2423 2466 2917 3010 3600 3782 4143
5	56 142 236 381 1050 1141 1372 1627 1985 2247 2340 3023 3434 3519 3957 4013 4142 4164 4279
6	298 1211 2548 3643
7	73 1070 1614 1748
8	1439 2141 3614
9	284 1564 2629
10	607 660 855
11	1195 2037 2753
12	49 1198 2562
13	296 1145 3540
14	1516 2315 2382
15	154 722 4016
16	759 2375 3825
17	162 194 1749
18	2335 2422 2632
19	6 1172 2583
20	226 1325 2428
21	585 2708 2769
22	255 2801 3181
23	2979 3720 4090
24	208 1428 4094
25	199 3743 3757
26	1229 2059 4282
27	458 1100 1387
28	1199 2481 3284
29	1161 1467 4060
30	959 3014 4144
31	2556 3960 4125
32	2809 3834 4318

As yet still another example of the design result in consideration of the additional conditions, in the case in which N_{ldpc} is 16200, a code rate is 13/15, and M is 360 (or $Q_{ldpc}=6$), indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group of the parity check matrix having the structure of FIG. 3 are shown by following Tables 14 and 15.

19

TABLE 14

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group															
0	37	144	151	199	220	498	510	589	731	808	955	1249	1264	1311		
	1377	1460	1520	1598	1707	1958	2055	2099	2154							
1	20	27	165	462	546	583	742	795	1095	1110	1129	1145	1159	1190		
	1254	1363	1383	1459	1718	1835	1870	1879	2108	2128						
2	288	362	463	505	688	691	745	861	1006	1083	1124	1175	1247	1275		
	1337	1353	1378	1506	1588	1632	1720	1868	1980	2135						
3	405	464	478	511	566	574	641	766	785	802	836	996	1128	1239	1247	
	1449	1491	1537	1616	1643	1668	1950	1975	2149							
4	86	192	245	357	363	374	700	713	852	903	992	1174	1245	1277	1342	
	1369	1381	1417	1463	1712	1900	1952	2053	2118							
5	101	327	378	550												
6	186	723	1318	1550												
7	118	277	504	1835												
8	199	407	1776	1965												
9	187	1253	1328	1975												
10	62	144	1163	2017												
11	100	475	572	2136												
12	431	865	1568	2055												
13	783	640	981	1172												
14	220	1038	1903	2147												
15	483	1318	1358	2118												
16	92	961	1709	1810												
17	112	403	1485	2042												
18	431	1110	1130	1365												
19	587	1008	1206	1588												
20	704	1113	1943													
21	375	1487	2100													
22	1507	1950	2110													
23	962	1611	2038													
24	554	1295	1501													
25	488	784	1446													
26	871	1935	1964													
27	54	1475	1504													
28	1579	1617	2074													
29	1856	1967	2131													
30	330	1582	2107													
31	40	1056	1809													
32	1110	1353	1410													
33	232	554	1939													
34	168	641	1099													
35	333	437	1556													
36	153	522	745													
37	719	931	1188													
38	237	638	1607													

TABLE 15

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group															
0	35	738	817	922	1007	1039	1076	1192	1219	1286	1425	1614	1751			
	1806	1876	2007	2042	2091											
1	23	322	489	566	637	772	811	876	1074	1253	1323	1554	1583	1675		
	1766	1977	1996	2018												
2	215	232	351	358	527	571	782	954	994	1286	1308	1449	1455	1471		
	1837	1985	2094	2102												
3	79	157	251	312	399	533	568	592	698	828	1060	1070	1305	1524		
	1893	2011	2060	2141												
4	45	121	330	500	520	805	863	915	938	994	1031	1050	1269	1559		
	1604	1692	1895	1957												
5	343	396	563	691	803	892	899	1146	1272	1294	1341	1389	1543			
	1636	1688	1748	1884	1941											
6	45	172	231	242	357	403	413	503	571	713	728	1094	1218	1309		
	1470	1538	1876	2028												
7	429	1010	1769													
8	573	1236	1919													
9	1327	1540	1686													
10	344	1198	2051													
11	293	1819	1850													
12	204	1450	1892													
13	278	1509	1603													
14	214	702	1421													
15	343	1846	1971													
16	560	1195	1757													

20

TABLE 15-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group															
5	17	1195	2092	2130												
	18	520	807	1158												
	19	144	626	1155												
	20	1724	1834	2101												
	21	721	1218	2045												
	22	785	974	2051												
10	23	447	778	1837												
	24	1429	1602	2123												
	25	1751	1971	2084												
	26	90	633	790												
	27	393	731	758												
	28	753	1082	1270												
15	29	1048	1366	1722												
	30	123	1607	1711												
	31	50	1383	1656												
	32	886	930	1403												
	33	504	521	1651												
	34	1022	1507	1833												
20	35	778	1326	1844												
	36	327	415	1088												
	37	981	1342	1411												
	38	155	1266	1372												

Here, it is to be noted that even if a parity-check matrix is changed such that orders of indices within sequences of each i-th column group in Tables 2 to 15 are changed, the changed parity-check matrix is a parity check matrix of the same code.

For example, a sequence corresponding to a zero (0)-th column group in Table 5 is arranged in an order of 380, 671, 699, 745, 1410, 1564. Even if an arranging order of this sequence is changed into 671, 699, 1410, 380, 1564, 745, it is a parity check matrix of the same code.

In addition, even if arranging orders of sequences of respective column groups in Tables 2 to 15 are changed, algebraic characteristics such as cycle characteristics, degree distribution, a minimum distance, and the like, on a graph of a code are not changed. Therefore, the case in which arranging orders of sequences shown in Tables 2 to 15 are changed may become one example of a result that may be derived through a code design method suggested in the present embodiment.

For example, even if arranging orders of the sequence 380, 671, 699, 745, 1410, 1564 of a zero (0)-th column group in Table 5 and a sequence 893, 1305, 2030 of a twelfth column group in Table 5 are changed to set the sequence of the zero (0)-th column group to 893, 1305, 2030 and set the sequence of the twelfth column group to 380, 671, 699, 745, 1410, 1564, cycle characteristics, degree distribution, a minimum distance, and the like, on a graph of the code are not changed (actually, since changing arranging orders of sequences of the respective column groups are the same as changing arranging orders of column groups within a parity check matrix, main algebraic characteristics are not changed).

In addition, a result of adding an integer multiple of Q_{ldpc} to all of the sequences of any column groups in Tables 2 to 15 may also become one example of a result that may be derived through the code design method suggested in the present embodiment since the algebraic characteristics such as the cycle characteristics, the degree distribution, or the like, on the graph of the code are not changed.

For example, as a result of adding a multiple of 6 to all indices 893, 1305, 2030 of the twelfth column group in Table 5 for $Q_{ldpc}=N_{ldpc}-K_{ldpc}$, also in the case of 899 (=893+6), 1311 (=1305+6), 2036 (=2030+6) or 911 (=893+6×3), 1323 (=1305+6×3), 2048 (=2030+6×3) as a specific example, the algebraic characteristics such as the cycle characteristics,

21

the degree distribution, the minimum distance, or the like, on the graph of the code are not changed (actually, since a sequence obtained as a result of adding a multiple of Q_{ldpc} to any sequence is a sequence in which only an order of columns present within a corresponding column group is rearranged, main algebraic characteristics are not changed).

Here, it is to be noted that in the case in which a value obtained by adding the multiple of Q_{ldpc} to a given sequence is a value of $(N_{ldpc}-K_{ldpc})$ or more, it is changed into a value obtained by applying a modulo operation for $(N_{ldpc}-K_{ldpc})$ to the value. For example, when 6×3 is added to all of a sequence 247, 328, 1778, 2040, 2051, 2151 of a second column group in Table 5, a sequence 265, 346, 1796, 2058, 2069, 2169 is resultantly generated. In this case, since $(N_{ldpc}-K_{ldpc})=2160$, modulo-2160 is applied to the sequence, thereby making it possible to represent the sequence as 265, 346, 1796, 2058, 2069, 9 or 9, 265, 346, 1796, 2058, 2069.

In addition, although the sequences are represented based on the structure of the parity check matrix of FIG. 3 in Tables 2 to 15, in the case of applying row permutation for rearranging an order of rows, column permutation for rearranging an order of columns, or the like, to the parity check matrix of FIG. 3, the parity check matrix may be represented in a form different from the structure of FIG. 3. However, since an operation such as the row permutation, the column permutation, and the like, does not change the algebraic characteristics of the LDPC code itself such as the cycle characteristics, the degree distribution, the minimum distance, or the like, the parity check matrices may be considered to be the same as each other.

That is, when any given parity check matrix may be changed into a parity check matrix having the structure as shown in FIG. 3 through appropriate row permutation and column permutation and the case in which sequences coincide with one another in Tables 2 to 15 when the changed parity check matrix is represented like the sequences represented in Tables 2 to 15 is present, it is decided that two parity check matrices are algebraically equivalent to each other.

Hereinafter, a process of encoding an LDPC code using a parity check matrix having the structure as shown in FIG. 3 will be described. As described above, the process of encoding an LDPC code is to determine a codeword satisfying a relational equation: parity check matrix \times codeword = 0. That is, the LDPC encoding process may be represented by $H \cdot C^T = 0$. Here, H is a parity check matrix, and C is a LDPC codeword.

Hereinafter, when it is assumed that LDPC encoded information word bits are $(i_0, i_1, \dots, i_{K_{ldpc}-1})$ and LDPC codeword its generated by LDPC encoding are $(c_0, c_1, \dots, c_{N_{ldpc}-1})$, a method for calculating LDPC codeword bits will be described.

First, since the LDPC code is a systematic code, $c_k (0 \leq k < K_{ldpc}-1)$ is set to be the same as i_k . In addition, remaining codeword bits are set to $p_k := c_{k+K_{ldpc}}$. Here, p_k indicates parity bits and may be calculated as described below.

Meanwhile, since the parity check matrix is defined as in Tables 2 to 15 according to an exemplary embodiment, a process to be described below may be applied in the case in which the parity check matrix is defined as in Tables 2 to 15.

First, when it is assumed that an entry denoted in a j -th position of an i -th row in Tables 2 to 15 is $q(i, j, 0)$, $q(i, j, 1) = q(i, j, 0) + Q_{ldpc} \cdot 1 \pmod{N_{ldpc}-K_{ldpc}}$ for $0 < j < 360$. Here, accumulation '+' means additions defined in a Galois field (GF) (2) (that is, additions in GF(2)). In addition, Q_{ldpc} , which is a magnitude at which each column is cyclically shifted in an information word sub-matrix, may be a value defined in each of Tables 2 to 15.

22

Meanwhile, when $q(i, j, 0)$ and $q(i, j, 1)$ are defined as described above, a process of calculating parity bits is as follows.

Step 1) parity bits are initialized to '0'. That is, $p_k = 0$ for $0 \leq k < N_{ldpc} - K_{ldpc}$.

Step 2) i and l are set so that $i := \lfloor k/360 \rfloor$ and $l := k \pmod{360}$ for all k values of $0 \leq k < K_{ldpc}$. Here, $\lfloor x \rfloor$ is the largest integer value among integers that are not larger than x . That is, $\lfloor 1.2 \rfloor = 1$. Then, i_k is added to $p_{q(i, j, 1)}$ for all j s as follows based on the set i and j values. That is, $p_{q(i, 0, 1)} = p_{q(i, 0, 1)} + i_k$, $p_{q(i, 1, 1)} = p_{q(i, 1, 1)} + i_k$, $p_{q(i, 2, 1)} = p_{q(i, 2, 1)} + i_k$, \dots , $p_{q(i, w(i)-1, 1)} = p_{q(i, w(i)-1, 1)} + i_k$ are calculated.

Here, $w(i)$ is the number of values of the i -th row in Tables 2 to 15 and means the number of ones (1s) of a column corresponding to i_k in the parity check matrix. That is, $w(i)$ means the number of ones (1s) of the column corresponding to i_k in the parity check matrix. In addition, $q(i, j, 0)$, which is an entry denoted in a j -th position of an i -th row in Tables 2 to 15, is an index of the parity bit, and indicates a position of a row at which one (1) is present in a column corresponding to i_k in the parity check matrix.

Step 3) $p_k = p_k + p_{k-1}$ is calculated for all k s satisfying $0 \leq k < N_{ldpc} - K_{ldpc}$ to calculate the parity bit p_k .

The parity bits are calculated by the above-mentioned method. As a result, the LDPC codeword bits $c_0, c_1, \dots, c_{N_{ldpc}-1}$ may be calculated.

Meanwhile, the LDPC encoding process as described above is only an example. Meanwhile, since the LDPC encoding is a process of calculating an LDPC codeword C satisfying $H \cdot C^T = 0$, various encoding methods may be present for the given parity check matrix.

For example, a scheme applied in a DVB-T2 standard may also be applied to the case in which the parity check matrix is defined as shown in Tables 2 to 15. Hereinafter, the LDPC encoding process depending on the scheme applied in the DVB-T2 standard will be schematically described using an example in which the parity check matrix is defined as in Table 5.

First, when it is assumed that information word bits having a length of K_{ldpc} are $[i_0, i_1, i_2, \dots, i_{K_{ldpc}-1}]$ and parity bits having a length of $N_{ldpc} - K_{ldpc}$ are $[p_0, p_1, p_2, \dots, p_{N_{ldpc}-K_{ldpc}-1}]$, the LDPC encoding may be performed by the following process.

Step 1) parity bits are initialized to '0'. That is,

$$p_0 = p_1 = p_2 = \dots = p_{N_{ldpc}-K_{ldpc}-1} = 0$$

Step 2) zero (0)-th information word bits i_0 are accumulated in parity bits having addresses of parity bits defined in a first row (that is, a row of $i=0$) of Table 5 as indices of the parity bits. This may be represented by following mathematical expression 5.

$$\begin{aligned} p_{380} &= p_{380} \oplus i_0 \\ p_{671} &= p_{671} \oplus i_0 \\ p_{699} &= p_{699} \oplus i_0 \\ p_{745} &= p_{745} \oplus i_0 \\ p_{1410} &= p_{1410} \oplus i_0 \\ p_{1564} &= p_{1564} \oplus i_0 \end{aligned} \quad (5),$$

where i_0 means a zero (0)-th information word bit, p_i means an i -th parity bit, and \oplus means a binary operation. According to the binary operation, $1 \oplus 1$ is 0, $1 \oplus 0$ is 1, $0 \oplus 1$ is 1, and $0 \oplus 0$ is 0.

23

Step 3) 359 remaining information word bits i_m ($m=1, 2, \dots, 359$) are accumulated in the parity bits. Here, the remaining information word bits may be information word bits belonging to the same column group as a column group to which i_0 belongs. Here, an address of the parity bit may be determined based on following mathematical expression 6.

$$(x+(m \bmod 360) \times Q_{ldpc}) \bmod (N_{ldpc} - K_{ldpc}) \quad (6)$$

Here, x is an address of a parity bit accumulator corresponding to the information word bit i_0 , and Q_{ldpc} , which is a size at which each column is shifted in a sub-matrix corresponding to the information word, is 6.

As a result, each of the information word bits i_m ($m=1, 2, \dots, 359$) are accumulated in each of the parity bits having the addresses of the parity bits calculated based on above mathematical expression 6 as indices. As an example, an operation as represented by following mathematical expression 7 may be performed on the information word bit i_1 .

$$\begin{aligned} P_{386} &= P_{386} \oplus i_1 \\ P_{677} &= P_{677} \oplus i_1 \\ P_{705} &= P_{705} \oplus i_1 \\ P_{751} &= P_{751} \oplus i_1 \\ P_{1416} &= P_{1416} \oplus i_1 \\ P_{1570} &= P_{1570} \oplus i_1 \end{aligned} \quad (7)$$

where i_1 means a 1-th information word bit, p_i means an i -th parity bit, and \oplus means a binary operation. According to the binary operation, $1 \oplus 1$ is 0, $1 \oplus 0$ is 1, $0 \oplus 1$ is 1, and $0 \oplus 0$ is 0.

Step 4) 360-th information word bits i_{360} are accumulated in parity bits having addresses of parity bits defined in a second row (that is, a row of $i=1$) of Table 5 as indices of the parity bits.

Step 5) 359 remaining information word bits belonging to the same group as a group to which the information word bits i_{360} belong are accumulated in the parity bits. Here, an address of the parity bit may be determined based on above mathematical expression 6. However, in this case, x is an address of a parity bit accumulator corresponding to the information word bits i_{360} .

Step 6) the processes of Step 4 and Step 5 are repeated for all of the column groups of Table 5.

Step 7) as a result, the parity bit p_i is calculated based on following mathematical expression 8. Here, i is initialized to one (1).

$$p_i = p_i \oplus p_{i-1}, i=1, 2, \dots, N_{ldpc} - K_{ldpc} - 1 \quad (8)$$

In above mathematical expression 8, p_i means is an i -th parity bit, N_{ldpc} means a length of the LDPC codeword, K_{ldpc} means a length of the information word in the LDPC codeword, and \oplus means a binary operation. According to the binary operation, $1 \oplus 1$ is 0, $1 \oplus 0$ is 1, $0 \oplus 1$ is 1, and $0 \oplus 0$ is 0.

As a result, the parity bits may be calculated in the above-mentioned scheme.

Meanwhile, an address of a parity bit appearing in a zero (0)-th column of an i -th column group is the same as an index of a row at which one (1) is positioned in the zero (0)-th column of the i -th column group. Therefore, indices of rows at which one (1) is positioned in an i -th column of a zero (0)-th column group of Tables 2 to 15 may be represented as addresses of the parity bits in the encoding process. Therefore, Tables 2 to 15 may mean "addresses of parity bit accumulators".

24

As described above, in the present embodiment, the LDPC encoding process is performed in various schemes, thereby making it possible to generate the LDPC codeword.

Meanwhile, the LDPC code may be decoded using an iterative decoding algorithm based on a sum-product algorithm on a bipartite graph arranged in FIG. 2. Here, the sum-product algorithm is a kind of message passing algorithm, which is an algorithm exchanging messages through edges on the bipartite graph and calculating and updating an output message from messages input to variable nodes or check nodes.

Hereinafter, a message passing operation generally used in at the time of LDPC decoding will be described with reference to FIG. 4, according to an exemplary embodiment.

FIGS. 4A and 4B illustrate a message passing operation in any check node and any variable node for LDPC decoding.

FIG. 4A illustrates a message passing operation in any check node and any variable node of an LDPC decoding apparatus.

In FIG. 4A, a check node m 400 and a plurality of variable nodes 410, 420, 430 and 440 connected to the check node m 400 are shown. In addition, $T_{n',m}$ shown in FIG. 4A indicates a message passing from the variable node n' 410 to the check node m 400, and $E_{n,m}$ indicates a message passing from the check node m 400 to the variable node n 430. Here, a set of all variable nodes connected to the check node m 400 is defined as $N(m)$, and a set except for the variable node n 430 in $N(m)$ is defined as $N(m) \setminus n$.

In this case, a message update rule based on the sum-product algorithm may be represented by following mathematical expressions 9.

$$|E_{n,m}| = \Phi \left[\sum_{n' \in N(m) \setminus n} \Phi(|T_{n',m}|) \right] \quad (9)$$

$$\text{Sign}(E_{n,m}) = \prod_{n' \in N(m) \setminus n} \text{sign}(T_{n',m})$$

where $\text{Sign}(E_{n,m})$ indicates a sign of the message $E_{n,m}$, and $E_{n,m}$ indicates a magnitude of the message $E_{n,m}$. Meanwhile, a function $\Phi(x)$ may be represented by following mathematical expression 10.

$$\Phi(x) = -\log \left(\tanh \left(\frac{x}{2} \right) \right) \quad (10)$$

Meanwhile, in FIG. 4B, a variable node x 450 and a plurality of check nodes 460, 470, 480 and 490 connected to the variable node 450 are shown. In addition, $E_{y',x}$ shown in FIG. 4B indicates a message passing from the check node y' 460 to the variable node x 450, and $T_{y,x}$ indicates a message passing from the variable node x 450 to the variable node y 480. Here, a set of all variable nodes connected to the variable node x 450 is defined as $M(x)$, and a set except for the check node y 480 in $M(x)$ is defined as $M(x) \setminus y$. In this case, a message update rule based on the sum-product algorithm may be represented by following mathematical expression 11.

$$T_{y,x} = E_x + \sum_{y' \in M(x) \setminus y} E_{y',x} \quad (11)$$

Here, E_x means an initial message value of the variable node x .

In addition, in the case in which a bit value of the node x is determined, it may be represented by following mathematical expression 12.

$$P_x = E_x + \sum_{y' \in M(x)} E_{y',x} \quad (12)$$

In this case, an encoding bit corresponding to the node x may be determined depending on a value of P_x .

Meanwhile, since the decoding method described with reference to FIGS. 4A and 4B is a general decoding method, a detailed description thereof will be omitted. However, a method (Frank R. Kschischang, Brendan J. Frey, and Hans-Andrea Loeliger, "Factor Graphs and the Sum-Product Algorithm," IEEE TRANSACTIONS ON INFORMATION THEORY, VOL. 47, NO. 2, FEBRUARY 2001, pp 498-519) other than the method described with reference to FIG. 4 may be applied in determining a message value passing from the variable node and the check node.

FIG. 5 is a block diagram showing a configuration of an encoding apparatus according to an exemplary embodiment. In this case, the encoding apparatus 500 may perform LDPC encoding described above.

As shown in FIG. 5, the encoding apparatus 500 includes an LDPC encoder 510. The LDPC encoder 510 may perform LDPC encoding on input bits based on a parity check matrix to generate an LDPC codeword. Here, the LDPC codeword may be configured of 16200 bits. That is, a length of the LDPC codeword may be 16200.

Here, the parity check matrix may have the same form as that of the parity check matrix 300 shown in FIG. 3.

In detail, the parity check matrix includes an information word sub-matrix and a parity sub-matrix.

Here, the information word sub-matrix is configured of a plurality of column groups each including M columns and is defined as a table indicating a position of a value of one (1) present in each M -th column. Here, M , which is an interval at which patterns of columns are repeated in the information word sub-matrix, may be 360. In addition, the parity sub-matrix may have a dual diagonal structure.

In this case, the LDPC encoder 510 may perform the LDPC encoding using parity check matrices differently defined depending on a code rate (that is, a code rate of the LDPC code).

For example, the LDPC encoder 510 may perform LDPC encoding using a parity check matrix defined as a table such as Table 2 or Table 6 in the case in which the code rate is 7/15 and perform LDPC encoding using a parity check matrix defined as a table such as Table 3, Table 7, Table 11 or Table 12 in the case in which the code rate is 9/15. In addition, the LDPC encoder 510 may perform LDPC encoding using a parity check matrix defined as a table such as Table 4, Table 8 or Table 13 in the case in which the code rate is 11/15 and perform LDPC encoding using a parity check matrix defined as a table such as Table 5, Table 9, Table 14 or Table 15 in the case in which the code rate is 13/15. In addition, the LDPC encoder 510 may perform LDPC encoding using a parity check matrix defined as a table such as Table 10 in the case in which the code rate is 5/15.

Meanwhile, since a detailed method for performing LDPC encoding has been described above, duplicate descriptions will be omitted.

Meanwhile, the encoding apparatus 500 may further include a memory (not shown) pre-storing information on a code rate, a codeword length, and a parity check matrix of a LDPC code therein, and the LDPC encoder 510 may perform LDPC encoding using this information. As the information on the parity check matrix, in the case in which the parity check matrix suggested in the present embodiment is used, an information word sub-matrix is configured of a plurality of column groups each including M columns and may include a table showing positions of value of one (1) present in each M -th column.

FIG. 6 is a block diagram showing a configuration of a transmitting apparatus according to an exemplary embodiment. As shown in FIG. 6, the transmitting apparatus 600 may include a Bose, Chaudhuri, Hocquenghem (BCH) encoder 610, an LDPC encoder 620, an interleaver 630, and a modulator 640.

The BCH encoder 610 performs BCH encoding on input bits and outputs a BCH codeword generated by the BCH encoding to the LDPC encoder 620.

In detail, the BCH encoder 610 performs the BCH encoding on the input bits $L=[i_0, i_1, \dots, i_{K_{bch}-1}]$ to generate $K_{ldpc}-K_{bch}$ BCH parity bits and generate a BCH codeword $I_{ldpc}=[i_0, i_1, \dots, i_{K_{ldpc}-1}]$.

The BCH codeword $I_{ldpc}=[i_0, i_1, \dots, i_{K_{ldpc}-1}]$, which is an information word for LDPC encoding, is input to the LDPC encoder 620. Since the BCH encoding, which is a well known technology, is disclosed in a document such as "Bose, R. C.; Ray-Chaudhuri, D. K. (March 1960), "On A Class of Error Correcting Binary Group Codes", Information and Control 3 (1): 68-79, ISSN 0890-5401", or the like, detailed descriptions thereof will be omitted.

Meanwhile, it may be changed whether or not the BCH encoder 610 is used. That is, in some cases, the BCH encoder 610 may also be omitted.

The LDPC encoder 620 performs LDPC encoding on the BCH codeword output from the BCH encoder 610 and outputs the LDPC codeword generated by the LDPC encoding to the interleaver 630.

In detail, the LDPC encoder 620 performs the LDPC encoding on the BCH codeword $I_{ldpc}=[i_0, i_1, \dots, i_{K_{ldpc}-1}]$ output from the BCH encoder 610 so as to be an information word to generate $N_{ldpc}-K_{ldpc}$ LDPC parity bits and generate the LDPC codeword $C_{ldpc}=[c_0, c_1, \dots, c_{N_{ldpc}-1}]$.

However, in the case in which the BCH encoder 610 is omitted, the LDPC encoder 620 may perform the LDPC encoding on the input bits.

Meanwhile, the LDPC encoder 620 of FIG. 6 may be implemented by the LDPC encoder 510 described with reference to FIG. 5. That is, the LDPC encoder 620 may perform the LDPC encoding using a parity check matrix including an information word sub-matrix defined depending on a code rate as shown in Tables 2 to 15 and a parity sub-matrix having a dual diagonal structure.

To this end, the transmitting apparatus 600 may include a memory (not shown) storing information on the parity check matrix therein. In this case, the parity check matrix may have various forms depending on the code rate, and the tables defined in Tables 2 to 15 may be an example. As the information on the parity check matrix, in the case in which the parity check matrix suggested in the present embodiment is used, an information word sub-matrix is configured of a plurality of column groups each including M columns and may include a table showing positions of value of one (1) present in each M -th column.

The interleaver **630** performs interleaving on the LDPC codeword output from the LDPC encoder **620** and output interleaved bits to the modulator **640**.

In this case, the interleaver **630** receives LDPC codeword bits output from the LDPC encoder **620** and perform the interleaving in a predetermined scheme. Various interleaving schemes may be present, and it may be varied whether or not the interleaver **630** is used.

The modulator **640** modulates bits output from the interleaver **630** in a serial-to-parallel form, thereby making it possible to generate a cell configured of a predetermined number of bits. Here, the number of bits configuring each cell may be the same as that of bits configuring a modulated symbol mapped to the constellation.

In detail, the modulator **640** may demultiplex the bits output from the interleaver **630** and map the demultiplexed bits to a constellation.

That is, the modulator **640** converts bits output from the interleaver **630** in a serial-to-parallel form, thereby making it possible to generate a cell configured of a predetermined number of bits. Here, the number of bits configuring each cell may be the same as that of bits configuring a modulated symbol mapped to the constellation.

Then, the modulator **640** may map the demultiplexed bits to the constellation. That is, the modulator **640** may modulate the demultiplexed bits in various modulation schemes such as quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (QAM), 64-QAM, 256-QAM, 1024-QAM, and 4096-QAM to generate the modulated symbols and may the modulated symbols to constellation points. In this case, since the demultiplexed bits configure the cell corresponding to the modulated symbol, the respective cells may be sequentially mapped to the constellation points.

In addition, the modulator **640** may modulate a signal mapped to the constellation and transmit the modulated signal to the receiving apparatus **900**. For example, the modulator **640** may map the signal mapped to the constellation to an orthogonal frequency division multiplexing (OFDM) frame in an OFDM scheme and transmit the signal to the receiving apparatus **900** through an allocated channel.

Meanwhile, the transmitting apparatus **600** may pre-store various parameters used for the encoding, the interleaving, and the modulation therein. Here, the parameter used for the encoding may be information on a code rate and a codeword length of a BCH code, and a code rate, a codeword length, and a parity check matrix of an LDPC code. In addition, the parameter used for the interleaving may be information on an interleaving rule, and the parameter used for the modulation may be information on a modulation scheme. As the information on the parity check matrix, in the case in which the parity check matrix suggested in the present embodiment is used, an information word sub-matrix is configured of a plurality of column groups each including M columns and may include a table showing positions of value of one (1) present in each M-th column.

In this case, operations of the respective components configuring the transmitting apparatus **600** may be performed using these parameters.

Meanwhile, although not shown, the transmitting apparatus **600** may further include a controller (not shown) for controlling an operation thereof in some cases.

In this case, the controller (not shown) may provide the information on the code rate and the codeword length of the BCH code to the BCH encoder **610** and provide the information on the code rate, the codeword length, and the parity check matrix of the LDPC code to the LDPC encoder **620**. In addition, the controller (not shown) may provide information on the interleaving scheme to the interleaver **630** and provide information on the modulation scheme to the modulator **640**. As the information on the parity check matrix, in the case in

which the parity check matrix suggested in the present embodiment is used, an information word sub-matrix is configured of a plurality of column groups each including M columns and may include a table showing positions of value of one (1) present in each M-th column.

FIG. 7 is a block diagram showing a configuration of a decoding apparatus according to an exemplary embodiment. As shown in FIG. 7, the decoding apparatus **700** may include an LDPC decoder **710**.

The LDPC decoder **710** may perform LDPC decoding on an LDPC codeword based on the parity check matrix. Here, the LDPC codeword may be configured of 16200 bits. That is, a length of the LDPC codeword may be 16200.

For example, the LDPC decoder **710** may pass a log likelihood ratio (LLR) value corresponding to LDPC codeword bits therethrough by an iterative decoding algorithm to perform the LDPC decoding, thereby generating information word bits.

Here, the LLR value, which is a channel value corresponding to the LDPC codeword bits, may be represented by various methods.

For example, the LLR value may be represented as a log value of a ratio of likelihood that bits transmitted from a transmitting side through a channel will be 0 to likelihood that the bits will be 1. In addition, the LLR value may be a bit value itself determined depending on hard decision or be a representative value determined depending on a section to which likelihood that the bits transmitted from the transmitting side will be 0 or 1 belongs.

In this case, the transmitting side may generate the LDPC codeword using the LDPC encoder **510** as shown in FIG. 5 and transmit the generated LDPC codeword.

Meanwhile, the parity check matrix used at the time of the LDPC decoding may have the same form as that of the parity check matrix **300** shown in FIG. 3.

In detail, the parity check matrix may include an information word sub-matrix and a parity sub-matrix.

Here, the information word sub-matrix is configured of a plurality of column groups each including M columns and is defined as a table showing positions of values of 1 present in each M-th column. Here, M, which is an interval between repeated column patterns in the information word sub-matrix, may be 360. In addition, the parity sub-matrix may have a dual diagonal structure.

In this case, the LDPC decoder **710** may perform the LDPC decoding using parity check matrices differently defined depending on a code rate (that is, a code rate of the LDPC code).

For example, the LDPC decoder **710** may perform the LDPC decoding using a parity check matrix defined as a table such as Table 2 or Table 6 in the case in which the code rate is 7/15 and perform the LDPC decoding using a parity check matrix defined as a table such as Table 3, Table 7, Table 11 or Table 12 in the case in which the code rate is 9/15. In addition, the LDPC decoder **710** may perform the LDPC decoding using a parity check matrix defined as a table such as Table 4, Table 8 or Table 13 in the case in which the code rate is 11/15 and perform the LDPC decoding using a parity check matrix defined as a table such as Table 5, Table 9, Table 14 or Table 15 in the case in which the code rate is 13/15. In addition, the LDPC decoder **710** may perform the LDPC decoding using a parity check matrix defined as a table such as Table 10 in the case in which the code rate is 5/15.

Meanwhile, as described above, the LDPC decoder **710** may perform the LDPC decoding using the iterative decoding algorithm. In this case, the LDPC decoder **710** may have a structure as shown in FIG. 8. However, since the iterative

29

decoding algorithm has been already known, a detailed configuration shown in FIG. 8 is only an example.

As shown in FIG. 8, the decoding apparatus 800 includes an input processor 811, a memory 812, a variable node operator 813, a controller 814, a check node operator 815, and an output processor 816.

The input processor 811 stores an input value therein. In detail, the input processor 811 stores an LLR value of a reception signal received through a radio channel.

The controller 814 determines a size of a block of the reception signal received through the radio channel, the number of values input to the variable node operator 813, an address value in the memory 812, the number of values input to the check node operator 815, an address value in the memory 812, and the like, based on a parity check matrix corresponding to a code rate.

According to an exemplary embodiment of the present embodiment, the LDPC decoder 710 may perform decoding based on a parity check matrix having a form of FIG. 3 in which indices of rows at which one (1) is positioned in the zero (0)-th column of the i-th column group are defined as shown in Tables 2 to 15.

The memory 812 stores input data and output data of the variable node operator 813 and the check node operator 815 therein.

The variable node operator 813 receives data from the memory 812 depending on information on an address of the input data and information on the number of input data received from the controller 814 and performs a variable node operation. Then, the variable node operator 813 stores variable node operation results in the memory 812 based on information on an address of the output data and information on the number of output data received from the controller 814. In addition, the variable node operator 813 inputs the variable node operation result to the output processor 816 based on data received from the input processor 811 and the memory 812. Here, the variable node operation has been described based on FIG. 4.

The check node operator 815 receives data from the memory 812 depending on information on an address of the input data and information on the number of input data received from the controller 814 and performs a check node operation. Then, the check node operator 815 stores check node operation results in the memory 812 depending on information on an address of the output data and information on the number of output data received from the controller 814. Here, the check node operation has been described based on FIG. 4.

The output processor 816 performs a hard decision on whether information word bits of a codeword of a transmitter are zero (0) or one (1) based on the data received from the variable node operator 813 and then outputs a result of the hard decision, and an output value of the output processor 816 becomes a finally decoded value. In this case, in FIG. 4, the hard decision may be performed based on the sum of all message values (an initial message value and the other message values input from the check nodes) input to one variable node.

Meanwhile, the decoding apparatus 700 may further include a memory (not shown) pre-storing information on a code rate, a codeword length, and a parity check matrix of an LDPC code therein, and the LDPC decoder 710 may perform the LDPC decoding using this information. However, this is only an example. That is, corresponding information may also be provided from the transmitting side. As the information on the parity check matrix, in the case in which the parity check matrix suggested in the present embodiment is used, an

30

information word sub-matrix is configured of a plurality of column groups each including M columns and may include a table showing positions of value of one (1) present in each M-th column.

FIG. 9 is a block diagram for describing a configuration of a receiving apparatus according to an exemplary embodiment of the present invention. As shown in FIG. 9, the receiving apparatus 900 includes a demodulator 910, a deinterleaver 920, an LDPC decoder 930, and a BCH decoder 940.

The demodulator 910 receives and demodulates a signal transmitted from the transmitting apparatus 600 (See FIG. 6). In detail, the demodulator 910 may demodulate the received signal to generate values corresponding to LDPC codewords and output the values to the deinterleaver 920.

In this case, the values corresponding to the LDPC codewords may be represented by channel values for the received signal. Here, various methods for determining the channel value may be present. As an example, a method for determining an LLR value may be used.

The deinterleaver 920 performs deinterleaving on the output values of the demodulator 910 and outputs deinterleaved values to the LDPC decoder 930.

In detail, the deinterleaver 920, which is a component corresponding to the interleaver 630 of the transmitting apparatus 600, may perform an operation corresponding to the interleaver 630. That is, the deinterleaver 920 may reversely apply the interleaving scheme applied by the interleaver 630 to deinterleave the LLR values output from the demodulator 910.

However, in some cases, when the interleaver 630 is omitted in the transmitting apparatus 600, the deinterleaver 920 may be omitted.

The LDPC decoder 930 may perform LDPC decoding using the output values of the deinterleaver 920 and output LDPC decoded bits to the BCH decoder 940. Here, the LDPC decoded bits may be a BCH codeword.

In detail, the LDPC decoder 930, which is a component corresponding to the LDPC encoder 620 of the transmitting apparatus 600, may perform the LDPC decoding based on a parity check matrix. Meanwhile, the LDPC decoder 930 of FIG. 9 may be implemented by the LDPC decoder 710 described with reference to FIG. 7. That is, the LDPC decoder 930 may perform the LDPC decoding using a parity check matrix including an information word sub-matrix defined depending on a code rate as shown in Tables 2 to 15 and a parity sub-matrix having a dual diagonal structure.

The BCH decoder 940 may perform BCH decoding on the output value of the LDPC decoder 930.

In detail, the BCH decoder 940, which is a component corresponding to the BCH encoder 610 of the transmitting apparatus 600, may perform the BCH decoding on the BCH codeword output from the LDPC decoder 930 to generate the bits transmitted from the transmitting apparatus 600. However, in some cases, when the BCH encoder 610 is omitted in the transmitting apparatus 600, the BCH decoder 940 may be omitted.

Meanwhile, the receiving apparatus 900 may pre-store various parameters used for the decoding and the deinterleaving therein. Here, the parameter used for the decoding may be information on a code rate and a codeword length of a BCH code, and a code rate, a codeword length, and a parity check matrix of an LDPC code. In addition, the parameter used for the deinterleaving may be information on a deinterleaving rule. As the information on the parity check matrix, in the case in which the parity check matrix suggested in the present embodiment is used, an information word sub-matrix is configured of a plurality of column groups each including M

columns and may include a table showing positions of value of one (1) present in each M-th column.

In this case, operations of the respective components configuring the receiving apparatus **900** may be performed using these parameters.

Meanwhile, although not shown, the receiving apparatus **900** may further include a controller (not shown) for controlling an operation thereof in some cases.

In this case, the controller (not shown) may provide the information on the code rate and the codeword length of the BCH code to the BCH decoder **940** and provide the information on the code rate, the codeword length, and the parity check matrix of the LDPC code to the LDPC decoder **930**. In addition, the controller (not shown) may also provide information on the interleaving scheme to the deinterleaver **920**. As the information on the parity check matrix, in the case in which the parity check matrix suggested in the present embodiment is used, an information word sub-matrix is configured of a plurality of column groups each including M columns and may include a table showing positions of value of one (1) present in each M-th column.

FIG. **10** is a flow chart for describing an encoding method according to an exemplary embodiment. In detail, FIG. **10** is a diagram for describing an encoding method of an encoding apparatus for performing LDPC encoding.

First, an LDPC codeword is generated by performing LDPC encoding on input bits based on a parity check matrix (**S1010**). Here, the LDPC codeword may be configured of 16200 bits. That is, a length of the LDPC codeword may be 16200.

Meanwhile, the parity check matrix may have the same form as that of the parity check matrix **300** shown in FIG. **3**.

In detail, the parity check matrix may include an information word sub-matrix and a parity sub-matrix.

Here, the information word sub-matrix may be configured of a plurality of column groups each including M columns and be defined as a table showing positions of value of one (1) present in each M-th column. Here, M, which is an interval between repeated column patterns in the information word sub-matrix, may be 360. In addition, the parity sub-matrix may have a dual diagonal form.

In this case, in **S1010**, the LDPC encoding may be performed using parity check matrices differently defined depending on code rates.

For example, the LDPC encoding may be performed using a parity check matrix defined as a table such as Table 2 or Table 6 in the case in which the code rate is 7/15 and may be performed using a parity check matrix defined as a table such as Table 3, Table 7, Table 11 or Table 12 in the case in which the code rate is 9/15. In addition, the LDPC encoding may be performed using a parity check matrix defined as a table such as Table 4, Table 8 or Table 13 in the case in which the code rate is 11/15 and may be performed using a parity check matrix defined as a table such as Table 5, Table 9, Table 14 or Table 15 in the case in which the code rate is 13/15. In addition, the LDPC encoding may be performed using a parity check matrix defined as a table such as Table 10 in the case in which the code rate is 5/15.

Meanwhile, since a detailed method for performing the LDPC encoding has been described above, duplicate descriptions will be omitted.

FIG. **11** is a flow chart for describing a decoding method according to an exemplary embodiment. In detail, FIG. **11** is a diagram for describing a decoding method of a decoding apparatus for performing LDPC decoding.

First, LDPC decoding is performed in an LDPC codeword based on a parity check matrix (**S1110**). Here, the LDPC

codeword may be configured of 16200 bits. That is, a length of the LDPC codeword may be 16200.

For example, an LLR value corresponding to LDPC codeword bits passes by an iterative decoding algorithm to perform the LDPC decoding, thereby making it possible to generate information word bits.

Here, the LLR value, which is a channel value corresponding to the LDPC codeword bits, may be represented by various methods.

For example, the LLR value may be represented as an LLR value that bits transmitted from a transmitting side through a channel will be 0 to likelihood that the bits will be 1. In addition, the LLR value may be a bit value itself determined depending on hard decision or be a representative value determined depending on a section to which likelihood that the bits transmitted from the transmitting side will be zero (0) or one (1) belongs.

In this case, the transmitting side may generate the LDPC codeword using the LDPC encoder **510** as shown in FIG. **5** and transmit the generated LDPC codeword.

Meanwhile, the parity check matrix may have the same form as that of the parity check matrix **300** shown in FIG. **3**.

In detail, the parity check matrix may include an information word sub-matrix and a parity sub-matrix.

Here, the information word sub-matrix is configured of a plurality of column groups each including M columns and is defined as a table showing positions of value of one (1) present in each M-th column. Here, M, which is an interval between repeated column patterns in the information word sub-matrix, may be 360. In addition, the parity sub-matrix may have a dual diagonal form.

In this case, in **S1110**, the LDPC decoding may be performed using parity check matrices differently defined depending on code rates.

For example, the LDPC decoding may be performed using a parity check matrix defined as a table such as Table 2 or Table 6 in the case in which the code rate is 7/15 and may be performed using a parity check matrix defined as a table such as Table 3, Table 7, Table 11 or Table 12 in the case in which the code rate is 9/15. In addition, the LDPC decoding may be performed using a parity check matrix defined as a table such as Table 4, Table 8 or Table 13 in the case in which the code rate is 11/15 and may be performed using a parity check matrix defined as a table such as Table 5, Table 9, Table 14 or Table 15 in the case in which the code rate is 13/15. In addition, the LDPC decoding may be performed using a parity check matrix defined as a table such as Table 10 in the case in which the code rate is 5/15.

Meanwhile, since a detailed method for performing the LDPC decoding has been described above, detailed descriptions will be omitted.

Meanwhile, a non-transitory computer readable medium in which programs for sequentially performing the encoding method and the decoding method according to an exemplary embodiment are stored may be provided.

The non-transitory computer readable medium is not a medium in which data are stored for a short moment, such as a register, a cache, a memory, or the like, but means a medium semi-permanently storing data therein and readable by a device. In detail, various applications or programs described above may be stored in and provided from the non-transitory computer readable medium such as a compact disk (CD), a digital versatile disk (DVD), a hard disk, a blu-ray disk, a universal serial bus (USB), a memory card, a read only memory (ROM), or the like.

In addition, although buses are not shown in block diagrams showing the encoding apparatus, the decoding appa-

ratus, the transmitting apparatus, and the receiving apparatus, communication between the respective components in the encoding apparatus, the decoding apparatus, the transmitting apparatus, and the receiving apparatus may also be performed through the buses.

Components, elements or units represented by a block as illustrated in FIGS. 5-9 may be embodied as the various numbers of hardware, software and/or firmware structures that execute respective functions described above, according to exemplary embodiments. For example, these components, elements or units may use a direct circuit structure, such as a memory, processing, logic, a look-up table, etc. that may execute the respective functions through controls of one or more microprocessors or other control apparatuses. These components, elements or units may be specifically embodied by a module, a program, or a part of code, which contains one or more executable instructions for performing specified logic functions. Also, at least one of the above components, elements or units may further include a processor such as a central processing unit (CPU) that performs the respective functions, a microprocessor, or the like.

As set forth above, according to various exemplary embodiments, LDPC encoding and decoding performance may be improved.

Further, although various exemplary embodiments of the inventive concept have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible, without departing from the scope and spirit of the inventive concept as disclosed in the accompanying claims. Accordingly, such modifications, additions and substitutions should also be understood to fall within the scope of the inventive concept.

What is claimed is:

1. An encoding apparatus for performing low density parity check (LDPC) encoding, comprising:

an LDPC encoder configured to generate an LDPC code-word formed of 16200 bits by performing the LDPC encoding on input bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column, wherein the LDPC encoder is configured to perform the LDPC encoding using the parity check matrix defined as a following table when a code rate of an LDPC code is 7/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group															
0	432	655	893	942	1285	1427	1738	2199	2441	2565	2932	3201	4144	4419	4678	4963
1	220	453	690	826	1116	1425	1488	1901	3119	3182	3568	3800	3953	4071	4782	5038
2	300	454	497	930	1757	2145	2314	2372	2467	2819	3191	3256	3699	3984	4538	4965
3	24	65	565	609	990	1319	1394	1465	1918	1976	2463	2987	3330	3677	4195	4240
4	1373	4668	5324	7777												
5	189	3930	5766	6877												
6	3	2961	4207	5747												
7	1108	4768	6743	7106												
8	1282	2274	2750	6204												
9	2279	2587	2737	6344												
10	2889	3164	7275	8040												
11	133	2734	5081	8386												
12	437	3203	7121													

-continued

Indices of rows at which 1s are positioned in
i 0-th column of i-th column group

13 4280 7128 8490
14 619 4563 6206
15 2799 6814 6991
16 244 4212 5925
17 1719 7657 8554
18 53 1895 6685
19 584 5420 6856
20 2958 5834 8103.

2. An encoding apparatus for performing low density parity check (LDPC) encoding, comprising:

an LDPC encoder configured to generate an LDPC code-word formed of 16200 bits by performing the LDPC encoding on input bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein the LDPC encoder is configured to perform the LDPC encoding using the parity check matrix defined as a following table when a code rate of an LDPC code is 5/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group															
0	245	449	491	980	1064	1194	1277	1671	2026	3186	4399	4900	5283	5413	5558	6570
	7492	7768	7837	7984	8306	8483	8685	9357	9642	10045	10179	10261	10338	10412		
1	1318	1584	1682	1860	1954	2000	2062	3387	3441	3879	3931	4240	4302	4446	4603	5117
	5588	5675	5793	5955	6097	6221	6449	6616	7218	7394	9535	9896	10009	10763		
2	105	472	785	911	1168	1450	2550	2851	3277	3624	4128	4460	4572	4669	4783	5102
	5133	5199	5905	6647	7028	7086	7703	8121	8217	9149	9304	9476	9736	9884		
3	1217	5338	5737	8334												
4	855	994	2979	9443												
5	7506	7811	9212	9982												
6	848	3313	3380	3990												
7	2095	4113	4620	9946												
8	1488	2396	6130	7483												
9	1002	2241	7067	10418												
10	2008	3199	7215	7502												
11	1161	7705	8194	8534												
12	2316	4803	8649	9359												
13	125	1880	3177													
14	1141	8033	9072													

3. An encoding apparatus for performing low density parity check (LDPC) encoding, comprising:

an LDPC encoder configured to generate an LDPC code-word formed of 16200 bits by performing the LDPC encoding on input bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein the LDPC encoder is configured to perform the LDPC encoding using the parity check matrix defined as a following table when a code rate of an LDPC code is 9/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	350 462 1291 1383 1821 2235 2493 3328 3353 3772 3872 3923 4259 4426 4542 4972 5347 6217 6246 6332 6386
1	177 869 1214 1253 1398 1482 1737 2014 2161 2331 3108 3297 3438 4388 4430 4456 4522 4783 5273 6037 6395
2	347 501 658 966 1622 1659 1934 2117 2527 3168 3231 3379 3427 3739 4218 4497 4894 5000 5167 5728 5975
3	319 398 599 1143 1796 3198 3521 3886 4139 4453 4556 4636 4688 4753 4986 5199 5224 5496 5698 5724 6123
4	162 257 304 524 945 1695 1855 2527 2780 2902 2958 3439 3484 4224 4769 4928 5156 5303 5971 6358 6477
5	807 1695 2941 4276
6	2652 2857 4660 6358
7	329 2100 2412 3632
8	1151 1231 3872 4869
9	1561 3565 5138 5303
10	407 794 1455
11	3438 5683 5749
12	1504 1985 3563
13	440 5021 6321
14	194 3645 5923
15	1217 1462 6422
16	1212 4715 5973
17	4098 5100 5642
18	5512 5857 6226
19	2583 5506 5933
20	784 1801 4890
21	4734 4779 4875
22	938 5081 5377
23	127 4125 4704
24	1244 2178 3352
25	3659 6350 6465
26	1686 3464 4336.

4. An encoding apparatus for performing low density parity check (LDPC) encoding, comprising:
 an LDPC encoder configured to generate an LDPC code-
 word formed of 16200 bits by performing the LDPC
 encoding on input bits based on a parity check matrix,
 wherein the parity check matrix includes an information
 word sub-matrix and a parity sub-matrix, and
 wherein the information word sub-matrix comprises a plu-
 rality of column groups each including 360 columns and
 being defined as a table indicating positions of one (1)
 present in each 360-th column,
 wherein the LDPC encoder is configured to perform the
 LDPC encoding using the parity check matrix defined as
 a following table when a code rate of an LDPC code is
 11/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	108 297 703 742 1345 1443 1495 1628 1812 2341 2559 2669 2810 2877 3442 3690 3755 3904 4264
1	180 211 477 788 824 1090 1272 1578 1685 1948 2050 2195 2233 2546 2757 2946 3147 3299 3544
2	627 741 1135 1157 1226 1333 1378 1427 1454 1696 1757 1772 2099 2208 2592 3354 3580 4066 4242
3	9 795 959 989 1006 1032 1135 1209 1382 1484 1703 1855 1985 2043 2629 2845 3136 3450 3742
4	230 413 801 829 1108 1170 1291 1759 1793 1827 1976 2000 2423 2466 2917 3010 3600 3782 4143
5	56 142 236 381 1050 1141 1372 1627 1985 2247 2340 3023 3434 3519 3957 4013 4142 4164 4279
6	298 1211 2548 3643
7	73 1070 1614 1748
8	1439 2141 3614
9	284 1564 2629
10	607 660 855
11	1195 2037 2753
12	49 1198 2562
13	296 1145 3540

-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
5	14 1516 2315 2382 15 154 722 4016 16 759 2375 3825 17 162 194 1749 18 2335 2422 2632 19 6 1172 2583
10	20 726 1325 1428 21 985 2708 2769 22 255 2801 3181 23 2979 3720 4090 24 208 1428 4094 25 199 3743 3757
15	26 1229 2059 4282 27 458 1100 1387 28 1199 2481 3284 29 1161 1467 4060 30 959 3014 4144 31 2666 3960 4125
20	32 2809 3834 4318.

5. An encoding apparatus for performing low density parity
 check (LDPC) encoding, comprising:
 an LDPC encoder configured to generate an LDPC code-
 word formed of 16200 bits by performing the LDPC
 encoding on input bits based on a parity check matrix,
 wherein the parity check matrix includes an information
 word sub-matrix and a parity sub-matrix, and
 wherein the information word sub-matrix comprises a plu-
 rality of column groups each including 360 columns and
 being defined as a table indicating positions of one (1)
 present in each 360-th column,
 wherein the LDPC encoder is configured to perform the
 LDPC encoding using the parity check matrix defined as
 a following table when the code rate of an LDPC code is
 13/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	37 144 161 199 220 496 510 589 731 808 834 965 1249 1264 1311 1377 1460 1520 1598 1707 1958 2055 2099 2154
1	20 27 165 462 546 583 742 796 1095 1110 1129 1145 1169 1190 1254 1363 1383 1463 1718 1835 1870 1879 2108 2128
2	288 362 463 505 638 691 745 861 1006 1083 1124 1175 1247 1275 1337 1353 1378 1506 1588 1632 1720 1868 1980 2135
3	405 464 478 511 566 574 641 766 785 802 836 996 1128 1239 1247 1449 1491 1537 1616 1643 1668 1950 1975 2149
4	86 192 245 357 363 374 700 713 852 903 992 1174 1245 1277 1342 1369 1381 1417 1463 1712 1900 1962 2053 2118
5	101 327 378 550
6	186 723 1318 1550
7	118 277 504 1835
8	199 407 1776 1965
9	387 1253 1328 1975
10	62 144 1163 2017
11	100 475 572 2136
12	431 865 1568 2055
13	283 640 981 1172
14	220 1038 1903 2147
15	483 1318 1358 2118
16	92 961 1709 1810
17	112 403 1485 2042
18	431 1110 1130 1365
19	587 1005 1206 1588
20	704 1113 1943
21	375 1487 2100
22	1507 1950 2110
23	962 1613 2038
24	554 1295 1501
25	488 784 1446

37

-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
26	871 1935 1964
27	54 1475 1504
28	1579 1617 2074
29	1856 1967 2131
30	330 1582 2107
31	40 1056 1809
32	1310 1353 1410
33	232 554 1939
34	168 641 1099
35	333 437 1556
36	153 622 745
37	719 931 1188
38	237 638 1607.

6. An encoding method for performing LDPC encoding, comprising:

generating an LDPC codeword formed of 16200 bits by performing the LDPC encoding on input bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein in the generating the LDPC codeword, the LDPC encoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 7/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	432 655 893 942 1285 1427 1738 2199 2441 2565 2932 3201 4144 4419 4678 4963 5423 5922 6433 6564 6656 7478 7514 7892
1	220 453 690 826 1116 1425 1488 1901 3119 3182 3568 3800 3953 4071 4782 5038 5555 6836 6871 7131 7609 7850 8317 8443
2	300 454 497 930 1757 2145 2314 2372 2467 2819 3191 3256 3699 3984 4538 4965 5461 5742 5912 6135 6649 7636 8078 8455
3	24 65 565 609 990 1319 1394 1465 1918 1976 2463 2987 3330 3677 4195 4240 4947 5372 6453 6950 7066 8412 8500 8599
4	1373 4668 5324 7777
5	189 3930 5766 6877
6	3 2961 4207 5747
7	1108 4768 6743 7106
8	1282 2274 2750 6204
9	2279 2587 2737 6344
10	2889 3164 7275 8040
11	133 2734 5081 8386
12	437 3203 7121
13	4280 7128 8490
14	619 4563 6206
15	2799 6814 6991
16	244 4212 5925
17	1719 7657 8554
18	53 1895 6685
19	584 5420 6856
20	2958 5834 8103.

7. An encoding method for performing LDPC encoding, comprising:

generating an LDPC codeword formed of 16200 bits by performing the LDPC encoding on input bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and

38

being defined as a table indicating positions of one (1) present in each 360-th column,

wherein in the generating the LDPC codeword, the LDPC encoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 5/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	245 449 491 980 1064 1194 1277 1671 2026 3186 4399 4900 5283 5413 5558 6570 7492 7768 7837 7984 8306 8483 8685 9357 9642 10045 10179 10261 10338 10412
1	1318 1584 1682 1860 1954 2000 2062 3387 3441 3879 3931 4240 4302 4446 4603 5117 5588 5675 5793 5955 6097 6221 6449 6616 7218 7394 9535 9896 10009 10763
2	105 472 785 911 1168 1450 2550 2851 3277 3624 4128 4460 4572 4669 4783 5102 5133 5199 5905 6647 7028 7086 7703 8121 8217 9149 9304 9476 9736 9884
3	1217 5338 5737 8334
4	855 994 2979 9443
5	7506 7811 9212 9982
6	848 3313 3380 3990
7	2095 4113 4620 9946
8	1488 2396 6130 7483
9	1002 2241 7067 10418
10	2008 3199 7215 7502
11	1161 7705 8194 8534
12	2316 4803 8649 9359
13	125 1880 3177
14	1141 8033 9072.

8. An encoding method for performing LDPC encoding, comprising:

generating an LDPC codeword formed of 16200 bits by performing the LDPC encoding on input bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein in the generating the LDPC codeword, the LDPC encoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 9/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	350 462 1291 1383 1821 2235 2493 3328 3353 3772 3872 3923 4259 4426 4542 4972 5347 6217 6246 6332 6386
1	177 869 1214 1253 1398 1482 1737 2014 2161 2331 3108 3297 3438 4388 4430 4456 4522 4783 5273 6037 6395
2	347 501 658 966 1622 1659 1934 2117 2527 3168 3231 3379 3427 3739 4218 4497 4894 5000 5167 5728 5975
3	319 398 599 1143 1796 3198 3521 3886 4139 4453 4556 4636 4688 4753 4986 5199 5224 5496 5698 5724 6123
4	162 257 304 524 945 1695 1855 2527 2780 2902 2958 3439 3484 4224 4769 4928 5156 5303 5971 6358 6477
5	807 1695 2941 4276
6	2652 2857 4660 6358
7	329 2100 2412 3632
8	1151 1231 3872 4869
9	1561 3565 5138 5303
10	407 794 1455
11	3438 5683 5749
12	1504 1985 3563
13	440 5021 6321
14	194 3645 5923
15	1217 1462 6422
16	1212 4715 5973

-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
17	4098 5100 5642
18	5512 5857 6226
19	2583 5506 5933
20	784 1801 4890
21	4734 4779 4875
22	938 5081 5377
23	127 4125 4704
24	1244 2178 3352
25	3659 6350 6465
26	1686 3464 4336.

9. An encoding method for performing LDPC encoding, comprising:

generating an LDPC codeword formed of 16200 bits by performing the LDPC encoding on input bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein in the generating the LDPC codeword, the LDPC encoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 11/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	108 297 703 742 1345 1443 1495 1628 1812 2341 2559 2669 2810 2877 3442 3690 3755 3904 4264
1	180 211 477 788 824 1090 1272 1578 1685 1948 2050 2195 2233 2546 2757 2946 3147 3299 3544
2	627 741 1135 1157 1226 1333 1378 1427 1454 1696 1757 1772 2099 2208 2592 3354 3580 4066 4242
3	9 795 959 989 1006 1032 1135 1209 1382 1484 1703 1855 1985 2043 2629 2845 3136 3450 3742
4	230 413 801 829 1108 1170 1291 1759 1793 1827 1976 2000 2423 2466 2917 3010 3600 3782 4143
5	56 142 236 381 1050 1141 1372 1627 1985 2247 2340 3023 3434 3519 3957 4013 4142 4164 4279
6	298 1211 2548 3643
7	73 1070 1614 1748
8	1439 2141 3614
9	284 1564 2629
10	607 660 855
11	1195 2037 2753
12	49 1198 2562
13	296 1145 3540
14	1516 2315 2382
15	154 722 4016
16	759 2375 3825
17	162 194 1749
18	2335 2422 2632
19	6 1172 2583
20	726 1325 1428
21	985 2708 2769
22	255 2801 3181
23	2979 3720 4090
24	208 1428 4094
25	199 3743 3757
26	1229 2059 4282
27	458 1100 1387
28	1199 2481 3284
29	1161 1467 4060
30	959 3014 4144
31	2666 3960 4125
32	2809 3834 4318.

10. An encoding method for performing LDPC encoding, comprising:

generating an LDPC codeword formed of 16200 bits by performing the LDPC encoding on input bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein in the generating the LDPC codeword, the LDPC encoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 13/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	37 144 161 199 220 496 510 589 731 808 834 965 1249 1264 1311 1377 1460 1520 1598 1707 2055 2099 2154
1	20 27 165 462 546 583 742 796 1095 1110 1129 1145 1169 1190 1254 1363 1383 1463 1718 1835 1870 1879 2108 2128
2	288 362 463 505 638 691 745 861 1006 1083 1124 1175 1247 1275 1337 1353 1378 1506 1588 1632 1720 1868 1980 2135
3	405 464 478 511 566 574 641 766 785 802 836 996 1128 1239 1247 1449 1491 1537 1616 1643 1668 1950 1975 2149
4	86 192 245 357 363 374 700 713 852 903 992 1174 1245 1277 1342 1369 1381 1417 1463 1712 1900 1962 2053 2118
5	101 327 378 550
6	186 723 1318 1550
7	118 277 504 1835
8	199 407 1776 1965
9	387 1253 1328 1975
10	62 144 1163 2017
11	100 475 572 2136
12	431 865 1568 2055
13	283 640 981 1172
14	2201038 1903 2147
15	483 1318 1358 2118
16	92 961 1709 1810
17	112 403 1485 2042
18	431 1110 1130 1365
19	587 1005 1206 1588
20	704 1113 1943
21	375 1487 2100
22	1507 1950 2110
23	962 1613 2038
24	554 1295 1501
25	488 784 1446
26	871 1935 1964
27	54 1475 1504
28	1579 1617 2074
29	1856 1967 2131
30	330 1582 2107
31	40 1056 1809
32	1310 1353 1410
33	232 554 1939
34	168 641 1099
35	333 437 1556
36	153 622 745
37	719 931 1188
38	237 638 1607.

11. A decoding apparatus for performing LDPC decoding, comprising:

an LDPC decoder configured to perform the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

41

wherein the LDPC decoder is configured to perform the LDPC decoding using a parity check matrix defined as the following table when a code rate of an LDPC code is 7/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	432 655 893 942 1285 1427 1738 2199 2441 2565 2932 3201 4144 4419 4678 4963 5423 5922 6433 6564 6656 7478 7514 7892
1	220 453 690 826 1116 1425 1488 1901 3119 3182 3568 3800 3953 4071 4782 5038 5555 6836 6871 7131 7609 7850 8317 8443
2	300 454 497 930 1757 2145 2314 2372 2467 2819 3191 3256 3699 3984 4538 4965 5461 5742 5912 6135 6649 7636 8078 8455
3	24 65 565 609 990 1319 1394 1465 1918 1976 2463 2987 3330 3677 4195 4240 4947 5372 6453 6950 7066 8412 8500 8599
4	1373 4668 5324 7777
5	189 3930 5766 6877
6	3 2961 4207 5747
7	1108 4768 6743 7106
8	1282 2274 2750 6204
9	2279 2587 2737 6344
10	2889 3164 7275 8040
11	133 2734 5081 8386
12	437 3203 7121
13	4280 7128 8490
14	619 4563 6206
15	2799 6814 6991
16	244 4212 5925
17	1719 7657 8554
18	53 1895 6685
19	584 5420 6856
20	2958 5834 8103.

12. A decoding apparatus for performing LDPC decoding, comprising:

A LDPC decoder configured to perform the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column, wherein the LDPC decoder is configured to perform the LDPC decoding using the parity check matrix defined as a following table when a code rate of an LDPC code is 5/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	245 449 491 980 1064 1194 1277 1671 2026 3186 4399 4900 5283 5413 5558 6570 7492 7768 7837 7984 8306 8483 8685 9357 9642 10045 10179 10261 10338 10412
1	1318 1584 1682 1860 1954 2000 2062 3387 3441 3879 3931 4240 4302 4446 4603 5117 5588 5675 5793 5955 6097 6221 6449 6616 7218 7394 9535 9896 10009 10763
2	105 472 785 911 1168 1450 2550 2851 3277 3624 4128 4460 4572 4669 4783 5102 5133 5199 5905 6647 7028 7086 7703 8121 8217 9149 9304 9476 9736 9884
3	1217 5338 5737 8334
4	855 994 2979 9443
5	7506 7811 9212 9982
6	848 3313 3380 3990
7	2095 4113 4620 9946
8	1488 2396 6130 7483
9	1002 2241 7067 10418
10	2008 3199 7215 7502
11	1161 7705 8194 8534
12	2316 4803 8649 9359
13	125 1880 3177
14	1141 8033 9072.

42

13. A decoding apparatus for performing LDPC decoding, comprising:

an LDPC decoder configured to perform the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein the LDPC decoder is configured to perform the LDPC decoding using the parity check matrix defined as a following table when a code rate of an LDPC code is 9/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	350 462 1291 1383 1821 2235 2493 3328 3353 3772 3872 3923 4259 4426 4542 4972 5347 6217 6246 6332 6386
1	177 869 1214 1253 1398 1482 1737 2014 2161 2331 3108 3297 3438 4388 4430 4456 4522 4783 5273 6037 6395
2	347 501 658 966 1622 1659 1934 2117 2527 3168 3231 3379 3427 3739 4218 4497 4894 5000 5167 5728 5975
3	319 398 599 1143 1796 3198 3521 3886 4139 4453 4556 4636 4688 4753 4986 5199 5224 5496 5698 5724 6123
4	162 257 304 524 945 1695 1855 2527 2780 2902 2958 3439 3484 4224 4769 4928 5156 5303 5971 6358 6477
5	807 1695 2941 4276
6	2652 2857 4660 6358
7	329 2100 2412 3632
8	1151 1231 3872 4869
9	1561 3565 5138 5303
10	407 794 1455
11	3438 5683 5749
12	1504 1985 3563
13	440 5021 6321
14	194 3645 5923
15	1217 1462 6422
16	1212 4715 5973
17	4098 5100 5642
18	5512 5857 6226
19	2583 5506 5933
20	784 1801 4890
21	4734 4779 4875
22	938 5081 5377
23	127 4125 4704
24	1244 2178 3352
25	3659 6350 6465
26	1686 3464 4336.

14. A decoding apparatus for performing LDPC decoding, comprising:

an LDPC decoder configured to perform the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein the LDPC decoder is configured to perform the LDPC decoding using the parity check matrix defined as a following table when a code rate of an LDPC code is 11/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	108 297 703 742 1345 1443 1495 1628 1812 2341 2559 2669 2810 2877 3442 3690 3755 3904 4264
1	180 211 477 788 824 1090 1272 1578 1685 1948 2050 2195 2233 2546 2757 2946 3147 3299 3544
2	627 741 1135 1157 1226 1333 1378 1427 1454 1696 1757 1772 2099 2208 2592 3354 3580 4066 4242
3	9 795 959 989 1006 1032 1135 1209 1382 1484 1703 1855 1985 2043 2629 2845 3136 3450 3742
4	230 413 801 829 1108 1170 1291 1759 1793 1827 1976 2000 2423 2466 2917 3010 3600 3782 4143
5	56 142 236 381 1050 1141 1372 1627 1985 2247 2340 3023 3434 3519 3957 4013 4142 4164 4279
6	298 1211 2548 3643
7	73 1070 1614 1748
8	1439 2141 3614
9	284 1564 2629
10	607 660 855
11	1195 2037 2753
12	49 1198 2562
13	296 1145 3540
14	1516 2315 2382
15	154 722 4016
16	759 2375 3825
17	162 194 1749
18	2335 2422 2632
19	6 1172 2583
20	726 1325 1428
21	985 2708 2769
22	255 2801 3181
23	2979 3720 4090
24	208 1428 4094
25	199 3743 3757
26	1229 2059 4282
27	458 1100 1387
28	1199 2481 3284
29	1161 1467 4060
30	959 3014 4144
31	2666 3960 4125
32	2809 3834 4318.

15. A decoding apparatus for performing LDPC decoding, comprising:

an LDPC decoder configured to perform the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix,

wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein the LDPC decoder is configured to perform the LDPC decoding using the parity check matrix defined as a following table when a code rate of an LDPC code is 13/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	37 144 161 199 220 496 510 589 731 808 834 965 1249 1264 1311 1377 1460 1520 1598 1707 1958 2055 2099 2154
1	20 27 165 462 546 583 742 796 1095 1110 1129 1145 1169 1190 1254 1363 1383 1463 1718 1835 1870 1879 2108 2128
2	288 362 463 505 638 691 745 861 1006 1083 1124 1175 1247 1275 1337 1353 1378 1506 1588 1632 1720 1868 1980 2135
3	405 464 478 511 566 574 641 766 785 802 836 996 1128 1239 1247 1449 4191 1537 1616 1643 1668 1950 1975 2149
4	86 192 245 357 363 374 700 713 852 903 992 1174 1245 1277 1342 1369 1381 1417 1463 1712 1900 1962 2053 2118
5	101 327 378 550
6	186 723 1318 1550
7	118 277 504 1835

-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
5	8 199 407 1776 1965 9 387 1253 1328 1975 10 62 144 1163 2017 11 100 475 572 2136 12 431 865 1568 2055 13 283 640 981 1172 14 220 1038 1903 2147 15 483 1318 1358 2118 16 92 961 1709 1810 17 112 403 1485 2042 18 431 1110 1130 1365 19 587 1005 1206 1588 20 704 1113 1943 21 375 1487 2100 22 1507 1950 2110 23 962 1613 2038 24 554 1295 1501 25 488 784 1446 26 871 1935 1964 27 54 1475 1504 28 1579 1617 2074 29 1856 1967 2131 30 330 1582 2107 31 40 1056 1809 32 1310 1353 1410 33 232 554 1939 34 168 641 1099 35 333 437 1556 36 153 622 745 37 719 931 1188 38 237 638 1607.

16. A decoding method for performing LDPC decoding, comprising:

performing the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein in the performing the LDPC decoding, the LDPC decoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 7/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	432 655 893 942 1285 1427 1738 2199 2441 2565 2932 3201 4144 4419 4678 4963 5423 5922 6433 6564 6656 7478 7514 7892
1	220 453 690 826 1116 1425 1488 1901 3119 3182 3568 3800 3953 4071 4782 5038 5555 6836 6871 7131 7609 7850 8317 8443
2	300 454 497 930 1757 2145 2314 2372 2467 2819 3191 3256 3699 3984 4538 4965 5461 5742 5912 6135 6649 7636 8078 8455
3	24 65 565 609 990 1319 1394 1465 1918 1976 2463 2987 3330 3677 4195 4240 4947 5372 6453 6950 7066 8412 8500 8599
4	1373 4668 5324 7777
5	189 3930 5766 6877
6	3 2961 4207 5747
7	1108 4768 6743 7106
8	1282 2274 2750 6204
9	2279 2587 2737 6344
10	2889 3164 7275 8040
11	133 2734 5081 8386
12	437 3203 7121
13	4280 7128 8490
14	619 4563 6206
15	2799 6814 6991
16	244 4212 5925

-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
17	1719 7657 8554
18	53 1895 6685
19	584 5420 6856
20	2958 5834 8103.

17. A decoding method for performing LDPC decoding, comprising:

performing the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column, wherein in the performing the LDPC decoding, the LDPC decoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 5/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	245 449 491 980 1064 1194 1277 1671 2026 3186 4399 4900 5283 5413 5558 6570 7492 7768 7837 7984 8306 8483 8685 9357 9642 10045 10179 10261 10338 10412
1	1318 1584 1682 1860 1954 2000 2062 3387 3441 3879 3931 4240 4302 4446 4603 5117 5588 5675 5793 5955 6097 6221 6449 6616 7218 7394 9535 9896 10009 10763
2	105 472 785 911 1168 1450 2550 2851 3277 3624 4128 4460 4572 4669 4783 5102 5133 5199 5905 6647 7028 7086 7703 8121 8217 9149 9304 9476 9736 9884
3	1217 5338 5737 8334
4	855 994 2979 9443
5	7506 7811 9212 9982
6	848 3313 3380 3990
7	2095 4113 4620 9946
8	1488 2396 6130 7483
9	1002 2241 7067 10418
10	2008 3199 7215 7502
11	1161 7705 8194 8534
12	2316 4803 8649 9359
13	125 1880 3177
14	1141 8033 9072.

18. A decoding method for performing LDPC decoding, comprising:

performing the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column, wherein in the performing the LDPC decoding, the LDPC decoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 9/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	350 462 1291 1383 1821 2235 2493 3328 3353 3772 3872 3923 4259 4426 4542 4972 5347 6217 6246 6332 6386

-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
1	177 869 1214 1253 1398 1482 1737 2014 2161 2331 3108 3297 3438 4388 4430 4456 4522 4783 5273 6037 6395
2	347 501 658 966 1622 1659 1934 2117 2527 3168 3231 3379 3427 3739 4218 4497 4894 5000 5167 5728 5975
3	319 398 599 1143 1796 3198 3521 3886 4139 4453 4556 4636 4688 4753 4986 5199 5224 5496 5698 5724 6123
4	162 257 304 524 945 1695 1855 2527 2780 2902 2958 3439 3484 4224 4769 4928 5156 5303 5971 6358 6477
5	807 1695 2941 4276
6	2652 2857 4660 6358
7	329 2100 2412 3632
8	1151 1231 3872 4869
9	1561 3565 5138 5303
10	407 794 1455
11	3438 5683 5749
12	1504 1985 3563
13	440 5021 6321
14	194 3645 5923
15	1217 1462 6422
16	1212 4715 5973
17	4098 5100 5642
18	5512 5857 6226
19	2583 5506 5933
20	784 1801 4890
21	4734 4779 4875
22	938 5081 5377
23	127 4125 4704
24	1244 2178 3352
25	3659 6350 6465
26	1686 3464 4336.

19. A decoding method for performing LDPC decoding, comprising:

performing the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column, wherein in the performing the LDPC decoding, the LDPC decoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 11/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	108 297 703 742 1345 1443 1495 1628 1812 2341 2559 2669 2810 2877 3442 3690 3755 3904 4264
1	180 211 477 788 824 1090 1272 1578 1685 1948 2050 2195 2233 2546 2757 2946 3147 3299 3544
2	627 741 1135 1157 1226 1333 1378 1427 1454 1696 1757 1772 2099 2208 2592 3354 3580 4066 4242
3	9 795 959 989 1006 1032 1135 1209 1382 1484 1703 1855 1985 2043 2629 2845 3136 3450 3742
4	230 413 801 829 1108 1170 1291 1759 1793 1827 1976 2000 2423 2466 2917 3010 3600 3782 4143
5	56 142 236 381 1050 1141 1372 1627 1985 2247 2340 3023 3434 3519 3957 4013 4142 4164 4279
6	298 1211 2548 3643
7	73 1070 1614 1748
8	1439 2141 3614
9	284 1564 2629
10	607 660 855
11	1195 2037 2753
12	49 1198 2562
13	296 1145 3540
14	1516 2315 2382
15	154 722 4016

47

-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
16	759 2375 3825
17	162 194 1749
18	2335 2422 2632
19	6 1172 2583
20	726 1325 1428
21	985 2708 2769
22	255 2801 3181
23	2979 3720 4090
24	208 1428 4094
25	199 3743 3757
26	1229 2059 4282
27	458 1100 1387
28	1199 2481 3284
29	1161 1467 4060
30	959 3014 4144
31	2666 3960 4125
32	2809 3834 4318.

20. A decoding method for performing LDPC decoding, comprising:

performing the LDPC decoding on an LDPC codeword formed of 16200 bits based on a parity check matrix, wherein the parity check matrix includes an information word sub-matrix and a parity sub-matrix, and

wherein the information word sub-matrix comprises a plurality of column groups each including 360 columns and being defined as a table indicating positions of one (1) present in each 360-th column,

wherein in the performing the LDPC decoding, the LDPC decoding is performed using the parity check matrix defined as a following table when a code rate of an LDPC code is 13/15:

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
0	37 144 161 199 220 496 510 589 731 808 834 965 1249 1264 1311 1377 1460 1520 1598 1707 1958 2055 2099 2154
1	20 27 165 462 546 583 742 796 1095 1110 1129 1145 1169 1190 1254 1363 1383 1463 1718 1835 1870 1879 2108 2128

48

-continued

i	Indices of rows at which 1s are positioned in 0-th column of i-th column group
5	2 288 362 463 505 638 691 745 861 1006 1083 1124 1175 1247 1275 1337 1353 1378 1506 1588 1632 1720 1868 1980 2135
3	405 464 478 511 566 574 641 766 785 802 836 996 1128 1239 1247 1449 1491 1537 1616 1643 1668 1950 1975 2149
4	86 192 245 357 363 374 700 713 852 903 992 1174 1245 1277 1342 1369 1381 1417 1463 1712 1900 1962 2053 2118
10	5 101 327 378 550
6	186 723 1318 1550
7	118 277 504 1835
8	199 407 1776 1965
9	387 1253 1328 1975
15	10 62 144 1163 2017
11	100 475 572 2136
12	431 865 1568 2055
13	283 640 981 1172
14	220 1038 1903 2147
15	483 1318 1358 2118
20	16 92 961 1709 1810
17	112 403 1485 2042
18	431 1110 1130 1365
19	587 1005 1206 1588
20	704 1113 1943
21	375 1487 2100
25	22 1507 1950 2110
23	962 1613 2038
24	554 1295 1501
25	488 784 1446
26	871 1935 1964
27	54 1475 1504
30	28 1579 1617 2074
29	1856 1967 2131
30	330 1582 2107
31	40 1056 1809
32	1310 1353 1410
35	33 232 554 1939
34	168 641 1099
35	333 437 1556
36	153 622 745
37	719 931 1188
40	38 237 638 1607.

* * * * *